Stream & Riparian
Resource Management

Natural Systems Design

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Subject: Lower Middle Fork Nooksack Geomorphic & Hydraulic Assessment

PROJECT BACKGROUND

The Middle Fork historically supported a healthy population of anadromous fish that included spring Chinook, coho, chum, pink, and sockeye salmon as well as coastal cutthroat and bull trout. Currently, many of these species are listed as threatened or endangered under the Endangered Species Act (ESA). Human actions such as timber harvest, removal of natural logjams, clearing of floodplain forests, channel confinement, bank armoring, loss of available side channels, and installation of road crossing structures have led to a general simplification of habitat within the Nooksack watershed and are attributed to the recent decline in salmon abundance in the Nooksack watershed (WRIA1, 2005). Within the Middle Fork watershed the following have been identified as the primary limiting factors for endangered early Chinook salmon (Lummi Natural Resources Department (LNRD), 2011);

1. Fish barriers to upstream migration,
2. Channel instability,
3. Lack of key habitat quantity and quality,
4. High stream temperatures, and
5. High sediment loads.

Since this project is intended to develop restoration designs from rivermile (RM) 0 to 5.0, fish barriers were not explicitly evaluated since this limiting factor is specific to the dam and diversion operated by the City of Bellingham upstream of the project reach. Specific to this project limiting factors 2 through 5 were deemed the most pertinent. The Nooksack Salmon Enhancement Association (NSEA) and Lummi Natural Resources (LNR) have identified the Lower Middle Fork Nooksack River (Middle Fork) as a candidate location for habitat restoration. The proposed restoration reach is between river mile (RM) 5 (upstream end) and RM 0 (downstream end) (Figure 1). This reach was targeted by NSEA for restoration following the recommendations put forth in the WRIA I Recovery Plan (WRIA 1 2005) for the entire Middle Fork Nooksack. The specific restoration goals for the project reach include:

- Improve long-term channel stability
- Promote the formation and growth of forested islands and associated side channels
- Increase key habitat quantity and quality through primary pool creation
- Increase the frequency of stable spawning habitat
- Stabilize naturally occurring accumulations of unstable large wood within the reach
- Increase floodplain and side channel connectivity.

Increases in these key habitat metrics would address limiting factors in the reach to ESA listed spring Chinook salmon, as well as other salmonids (pink, sockeye, fall Chinook, and coho) (WRIA 1 2005) that use the reach. Many of the project goals are anticipated to be met by increasing the number of stable accumulations of large wood debris (LWD) through the use of engineered logjams (ELJs). In addition to these improvements, higher LWD loading would increase the number of pools, provide additional hydraulic complexity leading to sorting of spawning gravels, reducing channel energy through stress partitioning, greater instream cover, and locally increased water elevations to improve side channel and floodplain connectivity.

Field surveys were conducted on 6/11/2013 and 8/18/2013 to evaluate the stability of naturally occurring LWD accumulations, current geomorphic processes active within the project reach, and existing habitat conditions. In addition, geomorphic responses from historic disturbances were evaluated to assess how current conditions reflect past impacts. These findings will be used to inform the development of conceptual restoration actions to improve habitat conditions by re-establishing geomorphic and habitat processes that contribute to increases in the key habitat metrics identified as goals for this project.

PROJECT REACH CHARACTERISTICS

The project reach is located in the lower 5 miles of the Middle Fork downstream of Mosquito Lake Road Bridge to the confluence with the North Fork Nooksack River. The drainage area for the project location is 89.8-square miles, with a vertical relief of 10,400-feet between headwaters on Mt. Baker and the valley bottom. Mean annual precipitation is 101-inches and mean annual discharge is 524-cubic feet per second (cfs) and peak discharges ranging from less than 3,000-cfs to nearly 14,000-cfs. The project reach on the Middle Fork lies in a broad alluvial plain with land use dominated by rural residential and small-scale agriculture. The average channel gradient is 0.9-percent and average valley gradient is 1.1-percent. Mean bankfull width is 140-ft and channel sinuosity (channel length:valley length) was determined as 1.24. The dominant substrate type in the reach ranges from coarse gravel to cobble, with bars comprised of sand and gravel.

HISTORIC ANTHROPOGENIC DISTURBANCE

The primary disturbance to the project reach impacting salmonid habitat is that from historic logging of the floodplain forest and adjacent hillslopes (LNRD 2011). Logging activities that contribute to salmonid habitat degradation include destabilization of the landscape from loss of soil root cohesion, reduction in LWD loading from removal of large trees from floodplain forests and clearing of LWD from the channel. The original old growth forest of the valley included huge Cedar, Douglas Fir, Western Hemlock, Grand Fir, Big Leaf Maple, and Black Cottonwood that attained diameters well over 6-ft and heights of more than 200-ft. These large riparian trees created stable snags when they fell into the river, that immediately formed stable habitat or went on to accumulated mobile LWD, creating larger logjams capable of re-directing the river. Timber harvests began in the late 19th century when logging practices included clearing trees on riparian floodplains and unstable steep slopes (LNRD 2011). Multiple large conifer stumps (>6-ft in diameter) were observed throughout the current active channel (active channel is the area of exposed and unvegetated alluvial deposits) and floodplain (Figure2). Cut marks for springboards observed on many of the stumps observed during the field reconnaissance suggest the largest “key-sized” timber was removed in the early 1900’s. Industrial logging continues within the watershed presently but current regulations are in place to limit harvest on streambanks, channel migration zones, floodplains, or unstable slopes. The impacts from these historic disturbances are recorded throughout the project reach and are associated with:

- Periods of channel instability [increased channel migration rates, rapid relocation of channel (channel avulsions)] due to reduced bank cohesion from root loss,
- Loss of hillslope cohesion from tree removal contributing to hillslope failure, and
- Loss of stable key pieces in the river channel and floodplain from direct removal and loss of riparian tree recruitment (Watts 1998).

These cumulative impacts have changed the river's morphology from a network of relatively narrow channels separated by forested islands into a much wider braided channel, dramatically diminishing habitat availability for salmonids throughout their life cycle (Collins and Sheikh 2002). Reductions in bank cohesion resulting from riparian deforestation directly contributes to channel widening (e.g., Eaton et al 2010) and introduces high sediment loads into the river from eroding banks. The loss of stable LWD, both key pieces (snags) and logjams, further compounded channel widening and braiding by removing structures that split flow, stabilized braid bars leading to mature forested channel islands.

RECENT RESTORATION ACTIONS

NSEA has been working in the Middle Fork (between RM 3 and 5) for over 10 years (2002 – present) to improve salmonid habitat conditions, and a brief overview of these projects is provided here based on information provided by NSEA. The first project was constructed during the summer of 2002 and 2003 between RM 4.3 and 4.6 in what was then a side channel, and included approximately 180 logs placed individually and in groups of 2- to 6-pieces (Figure 1). Key logs used were salvaged boom logs with 2- to 3-ft basal diameters and 40-ft in length. Additional LWD included conifer logs with a diameter at breast height (DBH) of 1.5-ft and a length of 30-ft and attached rootwads with diameters of 6- to10-ft. Grouped key logs were secured together with ½ in steel cable. Following a series of high flow events starting in 2004 the main channel avulsed into the side channel and mobilized the majority of the placed logs downstream, where they have accumulated in sub-reaches 4 and 5 (Figure 1), downstream of their original placement location.

A second project was constructed in 2010 at 3 locations along the Middle Fork (Figure 1). Approximately 200 conifer logs ranging from 2- to 3-ft DBH and 30- to 40-ft long with rootwads were helicopter placed in the left bank channel (post avulsion) from RM 4.6 to 4.8, and in the right bank channel (old main channel) from RM 3.9 to 4.5. An excavator was used to place the new key logs and 1-ft diameter, 16-ft long driven piles (8- to 10-ft depth) to secure existing LWD accumulations and create new LWD accumulations. New LWD accumulations consisted of 6- to10-pieces, with some secured using 2-in diameter manila rope. Additional new structures were installed along the right bank from RM 2.9 to 3.0. Much of the LWD placed as part of this 2010 project (particularly those from RM 3.9 to 4.5 along the right bank channel) are not engaged during low flow conditions, as the primary or low flow channel currently occupies the left bank channel within sub-reach 6. Flow has been observed in the right bank channel near RM 4.9 during flows approximately 1,600-cfs and higher (Figure 3). It is important to note that in the upstream most sub-reach the river channel avulsed sometime between 1986 and 1994 from the left side of its valley to the right, then moved back again between 2006 and 2009 (Figure 4).

GEOMORPHIC ANALYSIS

The Middle Fork originates from Deming glacier on the southwestern side of Mt. Baker, an active stratovolcano 10,781-ft in elevation in the northern Cascade Mountains. The mountain and underlying geology drive geomorphic processes in the Middle Fork, though many processes have been modified by anthropogenic actions. Historic glaciation, eruptions, and landslides have all contributed to the geomorphology of the Middle Fork, and continue to modify this evolving landscape.

The Middle Fork flows through Holocene alluvium from the confluence with the North Fork Nooksack River (North Fork) to Mosquito Lake Rd Bridge, upstream of which the valley is bedrock confined and intermittently mantled with Pleistocene glacial and Holocene landslide deposits (Lapen 2000) (Figure 5). The lower valley is bounded by the Bellingham Bay Member of the Chuckanut Formation on either side. A lahar (volcanic mudflow or debris flow) originating from Mt. Baker dated approximately 6,000 years ago (Kovanen 1996, Easterbrook and Kovanen 1996a, Hyde and Crandell 1978) and between 10 to 90 feet thick (Dragovich et al 1997) is exposed along the Lower Middle Fork (Figure 6), and forms discontinuous erosional terraces (15- to 20-ft high) along the lower valley margins. Holocene landslide deposits mantle the lower valley margin, particularly the northeastern side. Alluvial fans are present where larger tributaries enter the valley bottom (Figure 5). The 6,000 year old lahar is most prominent at the lower end of the valley, forming a high terrace along the southwestern (left) valley from near the confluence with the North Fork (RM 0.5) up to RM 1.7, and between RM 1.4 and 3.0 on the northeastern (right) side of the valley. Locations where this lahar is exposed have restricted channel migration over the period of recent record (1890 – 2013), probably due to the high cohesion of the lahar deposits (Figure 6). This resistance to erosion has formed a geologic control in the valley that limits channel occupancy where the lahar deposits are present.

Sediment production in the Middle Fork watershed are from mass-wasting, glacial advance and retreat, and from channel migration and avulsions (GeoEngineers 2011). Supply of sediment to the lower Middle Fork occurs primarily during high-flow events, and is via the mainstem channel and tributaries. Hillslope mass-wasting events contribute the most sediment to the Middle Fork (Lummi 2011), which have been exacerbated by historic landuse practices (Watts 1998). Retreat of the Deming Glacier since 1980 has exposed steep, unconsolidated lateral moraine deposits prone to failure (once buttressed by the glacier prior to retreat), and the presence of stagnant ice that can contribute to outburst floods (Watts 1998). These glacial processes can and have contribute large volumes of sediment as well to the Middle Fork, as described by Tucker (2013b) from a recent failure of lateral moraine deposits.

Large sediment producing events, and the events that ultimately mobilize the sediment and transport it downstream, can have significant impacts to the channel. Rapid aggradation can lead to avulsions of the channel, and rapid channel migration, both of which can recruit significant volumes of LWD to the channel. While these processes have been at work in the Middle Fork over geologic time, their rate has increased in recent time due to landuse and climate changes (Watts 1998, Lummi 2011). Historically, large sediment pulses would have been attenuated through local storage, resulting from considerably higher channel and floodplain roughness. This attenuation would have metered the delivery of sediment from large events through the systems, reducing the cumulative impact to habitat conditions at any given time.

TERRAIN ANALYSIS

As part of the geomorphic assessment for the reach, a terrain analysis was performed to evaluate the elevations of the floodplains and side channels relative to the main stem channel (Figure 7). The methods used for this analysis were adapted from Jones (2006), and utilized the LiDAR terrain surface (collected April 22nd 2011 at 220-cfs at USGS station 12208000, MF Nooksack River near Deming) (Watershed Sciences 2011). The resultant relative elevation map (REM) depicts elevations of floodplain and instream features relative to the water surface elevation of the channel at the time when the 2011 LiDAR was collected (channel centerline is highlighted in Figure 7). The results were field verified during the 6/11/2013 and 8/18/2013 surveys by comparing the bank heights with that predicted from the terrain analysis, and were found to be accurate to within 1-ft. The REM is useful in identifying side channels, potential avulsion (new channel) pathways, presence of terraces, and relic channel scars. Avulsion is the rapid abandonment of a river channel and the formation of a new river channel. Avulsions occur as a new channel forms creating a straighter path through the landscape, typically during large floods in areas where the new channel slope is greater than that of the old channel. Active side channels (both perennial and intermittent) are shown as shades of blue, with darker blues more frequently inundated (lower relative elevation). Similarly, floodplains that are inundated more frequently are shades of blue, with darker blues indicating more frequent inundation. Floodplains that are shades of green are inundated less frequently, with lighter greens to yellow only inundated during high flow events. The distribution of these features indicates areas where side channels are present and floodplains are relatively low (good floodplain connection), compared to areas where there are no side channels and floodplains are relatively high (disconnected floodplain).

In addition to the terrain analysis performed, historic active (unvegetated) channel positions (traced by Lummi Natural Resources, NSD; Figure 8) were compared to evaluate changes in channel location, timing of channel migration and avulsions, and incision. The REM (Figure 7) and historic channel alignments (Figure 8) were used to evaluate historic channel incision. Cross sections were extracted from the 2011 LiDAR at discrete locations, and the most recent active channel trace occupying each section of the cross section were combined to evaluate the relative position of historic channel alignments. This allows characterization in both horizontal (lateral bank erosion and avulsions) and vertical (aggradation and erosion) changes over time. This analysis does not account for overbank/floodplain sedimentation, and thus provides maximum incision rates. Plots and interpretations of these cross sections are provided below within the description of each sub-reach in which they occur.

The results of these analyses, coupled with reference literature and field observations, reveal the primary controls on geomorphic processes in the Middle Fork, and provide insight on how historic disturbances have altered these processes. Geologic controls set channel migration and avulsion potential to varying degrees throughout the Middle Fork. Four geologic units set this potential, with the degree to which they limit channel migration (including avulsions) decreasing from:

- Eocene Chuckanut Formation,
- Holocene lahar,
- Landslide deposits,
- Alluvial fan deposits, and
- Modern alluvium respectively.

Cumulatively, these geologic units form the boundary of historic (post-1890) channel occupation; however the potential exists for the channel to erode these units in the future. The distribution of these geologic units form distinct sub-reaches within the Middle Fork with unique hydraulic and sediment transport characteristics, which in turn drive geomorphic processes within the sub-reach. Six sub-reaches have been identified based on these criteria in the Middle Fork, and are described here to include the geologic controls and dominant processes driving channel form.

Sub-Reach 1 (RM 0 – 1.0)

The furthest downstream sub-reach (1) of the Middle Fork from RM 0 – 1.0 is characterized by a low gradient (0.76%) broad alluvial channel unconfined to RM 0.5, and bounded by the Canyon Creek alluvial fan on the right bank, and lahar deposits on the left bank to RM 1 (Figure 5). The lower end of this sub-reach is highly influenced by the North Fork, as the water and channel elevations in the North Fork control base level on the Middle Fork. Thus, the timing of flows on the North Fork can have a significant impact on hydraulic conditions and geomorphic processes within sub-reach 1. The glacially fed North Fork is generally more subject to channel migration. Canyon Creek enters the Middle Fork at RM 0.5 where it forms an alluvial fan. Changes in the course of Canyon Creek could influence patterns in the Lower Middle Fork. Between RM 0.5 and 1.0 the Middle Fork is constrained to the north by the Canyon Creek fan and to the south by the 6000-yr old lahar deposit. Between RM 0.0 and 0.5 the sub-reach has one of the widest historic channel migration zones (HCMZ) and is also subject to major changes in grade depending on channel length. In periods when the river meandered across the valley it increased its length and decreased its gradient. This in-turn could trigger aggradation of the channel which set the river up to avulse into low lying, but steeper floodplain channels that took a shorter path down the valley, triggering periods of incision (Figure 7). From 1938 to 1976 this section of the river lost channel length by moving to the south and incised about 4-ft (Figure 9). By 1986 the channel appears to have re-gained some channel length moving back to the north and aggrading 3 ft. Prior to 1994 the river avulsed into a more direct path down the south side of its valley and cut down over 4-ft from its 1986 elevation (Figure 9). The channel continued to incise until 2004 (net incision of 8.7-ft from 1986 channel), but has aggraded 2.1-ft since 2004. The overall trend from 1938 to 2011 has been about 8-ft of incision, at an average rate of 0.1-ft/yr. Noted incision is consistent with historic changes such as LWD removal, channel straightening, and bank armoring such as along the south (left) bank from RM 0.9 to 1.5. Increases in peak flows have also likely contributed to incision.

In general, the channel was located on the right (north) side of the valley from 1890 – 1976, and an avulsion was initiated by 1986 that shifted the channel toward the left (south) side of the valley (Figure 8). This pre-1986 avulsion represents the only location where the mapped lahar deposit has been significantly eroded in the period of record (1890 – present).

Riparian vegetation in this sub-reach is dominated by moderately sized mature forest on the left bank floodplain, which has not been harvested since prior to 1938. Pasture and agricultural clearings have been present near RM 0.5 since the beginning of the aerial photo record (1938), separated from the active channel by a 100-ft riparian buffer of trees larger than 50 ft. The right bank floodplain is comprised of young, dense forest, which began re-vegetating following the channel avulsion to the left bank in 1986. Much of the right bank contains trees between 10–50 ft tall. Patches of small, young alder are present on bars within the active floodplain.

Sub-Reach 2 (RM 1.0 – 1.5)

Sub-reach 2 from RM 1.0 – 1.5 remains low gradient (0.69%) and confined on the left bank by lahar deposits, but is unconfined on the right side until it hits the Canyon Creek alluvial fan around RM 1.2 (Figure 5). Review of the historic active channels shows rapid expansion of the channel toward the right bank, and significant channel widening (Figure 8). Erosion of the right bank has likely been exacerbated by clearing of the floodplain and conversion to farmland. Migrations rates up to 75-ft/year (between 2006 – 2009) toward the right bank demonstrate both the erodibility of the streambank material and the deposition of bed material passing through the sub-reach immediately upstream. The river goes from a supply limited sub-reach (sub-reach 3) to a transport limited sub-reach from 1.0 to 1.5, resulting in bar formation and active channel migration.

Much of the right bank forest in this sub-reach was cleared for agriculture and residential use prior to 1943 and remains un-forested to date. A narrow (100-ft) buffer of remnant forest along the right bank between RM 1.3 - 1.4 has remained intact and contains moderately sized trees (40-100 ft). RM 1.1 to 1.3 is largely un-forested, with patches of young forest (< 50 ft) near RM 1.2. The left bank has remained forested for at least 70 years with the exception of small residential clearings and contains young to mature secondary forest, increasing in age and height with distance from the active channel. Large trees (75 – 150 ft) surround many of the residential clearings.

Sub-Reach 3 RM (1.5 – 1.7)

Between RM 1.5 and 1.7 the Middle Fork is confined to a 500-ft wide corridor by lahar deposits on either side of the channel through the sub-reach (Figure 5). These deposits have restricted channel migration and avulsion through recorded history (post-1890), and have likely controlled channel forms following deposition of the lahar approximately 6,000 years ago (Kovanen 1996, Easterbrook and Kovanen 1996a, Hyde and Crandell 1978). Flow confinement (Figure 7) increases flow depths and velocities, creating a supply-limited transport reach with a very dynamic low-flow channel but relatively stable active channel (Figure 8). These hydraulic parameters would also suggest that stable LWD would be less frequent within this sub-reach owing to the higher velocities and depths associated with confinement of flood flows. The constriction of flow through the sub-reach also contributes to backwatering during large magnitude floods in the upstream sub-reach, which in turn contributes to geomorphic processes in that sub-reach.

Riparian vegetation on the left bank in this sub-reach is comprised of mature (> 70 years) second growth forest and small residential clearings at RM 1.7. These clearings are separated from the active channel by a 30- to 80-ft forested buffer of young trees (< 50 ft). The right bank floodplain contains a range of young to mature second growth forest, which continues to Mosquito Lake Road (680-ft forest buffer). The presence of lahar deposits on either side of the channel within this sub-reach has limited lateral erosion, providing the opportunity for mature forest development.

Sub-Reach 4 (RM 1.7 – 3.3)

The sub-reach (4) between RM 1.7 and 3.3 is low gradient (0.89%) and bounded by the Chuckanut Formation (Eocene) to the left (south), and Holocene lahar to the right (north) (Figure 5). This sub-reach doesn't have a significantly larger unvegetated channel width when compared to the more confined sub-reach downstream (sub-reach 3) (Figure 1), but the difference between the sub-reaches is clear looking at relative elevations (Figure 7). The unconfined width of sub-reach 4 is significantly wider (2,100-ft) than the confined downstream sub-reach 3 (500-ft wide) (Figure 7). Prior to the 6- to 8-ft of incision the river has experienced, sub-reach 3 would have created a much more significant constriction in the river that would have had a backwater effect upstream in sub-reach 4 during high flows (see hydraulic results section below). This backwater would have induced sediment deposition as flow velocities and sediment transport capacity decreased. Because the backwater effect is greatest during large magnitude floods, when high sediment loads are in transport, active channel locations within the sub-reach are susceptible to rapid aggradation and channel migration during such events. Aggradation of the active channel is the primary mechanism contributing to avulsion potential, and a review of the historic channel alignments demonstrates a high frequency of avulsions (new channel formations) within this sub-reach (Figure 8). A total of 5 channel avulsions ranging from 0.4 to 1.1 miles long are documented between 1943 and 1998. These avulsions include full avulsions of the active channel (from one side of the valley to the other) and partial avulsions (from one side of the valley to split between 2 channels). The full and partial avulsions within the sub-reach occur between two primary flow paths (between RM 1.7 and 2.4), with the channel alternating its location between the two. The active channel has remained along the left bank channel since 1998, and has incised 4.5-ft since 1994 based on current elevations of historic channel locations (Figure 10). Review of older historic channel elevations shows the 1986 and 1994 channel elevations were higher (both 1.5-ft higher) than in 1955. High sediment loads associated with the Porter Creek fire (September 1951) and subsequent mass wasting may have contributed to the channel aggradation evident in 1986 and 1994 aerial photos (GeoEngineers 2011).

Correlating avulsions with potential drivers is constrained by the time period between the historic channel alignments and aerial photos, making direct correlation to specific flood events difficult. It does appear that the timing of avulsions is not completely dependent on high flow events, as recent high flow events have not initiated avulsions within the sub-reach. This can be explained, at least in part, by channel incision since it would increase conveyance capacity in the downstream sub-reach 3 and decrease any backwater effect on this sub-reach 4. The timing of mass wasting events capable of delivering large volumes of sediment to the active channel could be responsible for localized channel aggradation and flow peaks that could contribute avulsion initiations. High flow events following mass wasting events with material in contact with the active channel would be capable of transporting significant sediment loads, contributing to channel aggradation and avulsion potential both during and after the flood event. On May 31st 2013 a significant debris flow occurred on the Middle Fork that was recorded by seismometers and downstream stream gaging stations. Large boulders up to 14-ft in diameter were transported downstream and deposited on floodplains 15-ft above the channel in the upper watershed (Tucker 2013a). The debris flow originated in the glacial moraine located at the terminus of the Deming Glacier in either 1974 or 1985, the Glacier has subsequently retreated about 1200-ft (Tucker 2013b). A second significant 2013 mass wasting event occurred 1.2 miles upstream of the Ridley Creek trail crossing on an older landslide scar, damming the river and creating a pond upstream (Tucker 2013c). Turbidity monitoring on the Nooksack River in Cedarville recorded significant spikes May 31st, and June 1st and 6th, indicating fine material from these events traveled through the Middle Fork, and transport of larger material capable of bed aggradation is likely to occur during the next high flow event. Thick sand deposits were observed during field reconnaissance along the active channel margins up to several feet thick, and are likely representative of material transported downstream from these recent events. It was observed during subsequent site visits that these sand deposits were mobilized during recent (late September 2013) high flows (approximately 2-year recurrence interval event). If larger material is mobilized into this sub-reach from these mass-wasting events during the next high flow event, rapid channel aggradation could occur and trigger channel changes. Depending on the magnitude of aggradation and remaining material upslope, an avulsion could occur either during the next high flow event, or during subsequent high flow events following the aggradation event.

The upper end of sub-reach 4, from RM 3.0 to 3.3, is characterized by lateral channel migration and incision, rather than the episodic aggradation and avulsions in the lower end of the sub-reach. Figure 11 shows a cross-section at RM 3.2 of the generalized 2011 LiDAR topography, demonstrating channel migration toward the left side of the valley, and incision up to 7.8-ft of incision and averaging 0.06-ft/yr (between 1890 to 2011). A maximum incision rate of 0.4-ft/yr was calculated between 1994 and 1998. This would indicate that this segment of the sub-reach is a supply limited transport reach, and the hydraulic conditions resulting from historic incision would increase flow depths and velocities during high flow events. This confinement due to incision and higher flow velocities would suggest LWD stability is less than in other locations along the Middle Fork where flow velocities and depths are less.

The left bank within this sub-reach from RM 1.7 to 2.2 is comprised of mature second growth forest with tree heights ranging from 50-200 ft as well as several residential clearings (between RM 2 and 1.7). The left bank floodplain from RM 2.2 to 3.2 was occupied by active channels through 1976 and contains younger forested stands. A large (0.6 square mile) forest stand was harvested between 1986 and 1994 on the valley wall, leaving a 200- to 700-ft buffer of second growth forest intact along the valley margin. The right bank floodplain in this sub-reach was occupied by active channels through 1994 (between RM 1.7 and 2.4), resulting in younger forest cover (< 50 ft). Portions of the right bank contain no riparian buffer (e.g. RM 2.9 – 3) due to residential and agricultural clearing prior to 1947.

Sub-Reach 5 (3.3 – 3.7)

The Middle Fork between RM 3.3 and 3.7 is characterized by a low gradient (1.16%), relatively stable unvegetated channel location; with a transient low flow channel that frequently migrates within the unvegetated channel limits (Figure 7). The channel is bounded by alluvial fan and landslide deposits on the left (Dragovich et al 1997), and recent alluvium on the right (north) (Lapen 2000). Well boring data obtained from Washington State Department of Ecology indicates that the Holocene lahar deposit is present at depth (22- to 30-ft below ground) along the right side of the valley within the sub-reach. The presence of the lahar unit at depth would contribute to stability within the sub-reach, and is likely inhibiting lateral migration into the mapped alluvium. A review of the historic channel alignments shows that there are no recorded avulsions within the sub-reach (Figure 8), and channel migration is largely limited to migration of the low-flow channel within the active channel limits (Figure 8). The unstable nature of the low-flow channel creates transient islands within the sub-reach that are frequently eroded and re-formed. Much of the riparian vegetation in this sub-reach is mature second growth greater than 70-years in age, with younger stands growing on transient bars in the active channel floodplain. Limited channel migration has allowed the growth of some large trees (> 150 ft) on both the left and right banks. Trees up to 250 ft tall are present on the left bank valley slope.

Sub-Reach 6 (3.7 – 5.0)

The furthest upstream sub-reach (6) from RM 3.7 to 5.0 is bounded by the Chuckanut Formation (Eocene) to the left (south), and Holocene alluvial fan (Porter Creek) and undifferentiated Pleistocene glacial deposits to the right (north) (Figure 5). Upstream of RM 5.0 the Middle Fork flows down a highly confined and steep bedrock channel. The Mosquito Lake Road Bridge crosses the river in the lower portion of the bedrock reach. The valley widens around RM 5.0 and the river channel transitions to alluvial pool-riffle morphology (Figure 7). As high flows enter this lower gradient (1.14%) sub-reach they expand, reducing in depth, velocity, and sediment transport capacity. This condition is much like an alluvial fan, where steep tributary streams drop high sediment loads once they reach the valley bottom. And similar to alluvial fans, the channel within this sub-reach is prone to frequent migration and avulsions in response to sediment deposition events. The timing of channel aggradation events does not directly correlate to high peak flow events (Table 1). Events with high sediment supply and limited transport capacity would be most closely linked to aggradation, which would correspond more to upstream mass wasting events than peak flows.

Historic active channel alignments show that the channel occupies 1 of 2 primary flow paths over the period of record, one down the right side of the valley and one down the left side (Figure 8). The only historic alignment that is not shown down either of these channels is the 1890 channel, which is less spatially accurate than those digitized from aerial photographs. The channel remains in the left channel from 1918 – 1955 (RM 4.1 – 5) with minimal lateral erosion, however islands form within the active channel between 1947 and 1955. Downstream of RM 4.1 there are 2 avulsions that occurred between 1918 and 1938 (Figure 8). A 0.2-mile long partial avulsion between RM 3.9 and 4.1 forms a flow split at RM 4.1, with a new flow path on the right side of the 1918 channel. A full avulsion of the channel from RM 3.7 to 4.0 shifted the channel toward the left. The channel avulses between 1918 and 1938 down a left flow path. Flow remains split into multiple channel threads between RM 3.7 and 4.1 through 1966 (Figure 8). The meander bend downstream of Mosquito Lake Road Bridge starts migrating toward the right between 1955 and 1966, and continues to migrate toward the right channel until a partial avulsion occurs between 1986 and 1994 (Figure 8). This partial avulsion maintains a flow split at RM 4.7 until the channel fully avulses into the right channel between 1986 and 1994. The channel remains in the right channel until a partial avulsion of the channel between 2006 and 2009, creating a flow split at RM 4.85. Following 2009, the percent of flow down the left channel path has increased, and all flows less than approximately 1,600-cfs now flow down the left flow path. During the most recent avulsion a large debris jam formed near RM 4.3 (Figure 12) as flow widened the left bank channel and subsequently recruited the developing riparian forest. Since depositing the large wood debris jam the channel has migrated westward and incised isolating the debris jam from the channel.

Riparian vegetation in this sub-reach is predominantly young forest along the active channel margins of the left and right bank avulsion channels with mature second growth in the floodplain. These 2 active channel flow paths are separated by a large, relatively stable vegetated island of second growth forest with tree heights ranging from 50-200 ft. Most of the forest on the left and right banks has not been harvested since prior to 1943, with the exception of small clearings on the right bank near RM 4.3 and the left bank near RM 4.7, which occurred in the early 1990's. This sub reach contains trees up to 250 ft in height. Channel migration and avulsions within this sub-reach recruit large second growth trees from the stable vegetated island, which form logjams and forces channel adjustments (further channel migration and avulsions).

LARGE WOOD ASSESSMENT

The LNRD assessed in-stream wood as part of the MFN River Habitat Assessment (2011). Findings suggest that LWD accumulations are common in the lower five miles of the Middle Fork. Washington State Forest Practices Board (1997) defines key-sized wood pieces as greater than 320 cubic feet in volume for channels with bankfull widths exceeding 65 feet. Using this definition, 66 key-sized pieces were recorded between

RM 0 and RM 5 in 2008, the majority of which were located at the edge of low flow channels and lateral bars (LNRD 2011). Mean LWD distributions for the Nooksack basin are approximately one key piece every 1,300 feet of channel and one logjam for each 2000 feet of channel (Brown and Maudlin, 2007). Woody debris accumulation density is affected by channel confinement, with higher LWD frequencies corresponding to areas where the confined channel transitions to a braided or meandering alignment (e.g. RM 3.2, RM 4.8) with 65 percent of the key-sized pieces occurring in the 2.6 miles of channel downstream of Mosquito Lake Rd. Bridge (LNRD 2011) (Figure 13). This pattern is attributed to the low-gradient, unconfined, and braided nature of the channel in this reach. Assessments of logjam stability suggest that LWD accumulations without key-sized pieces are more prone to mobilization. Due to historic old growth timber harvest in the riparian area, valley floodplain, and channel migration trends the majority of LWD in the Middle Fork is derived from relatively young, secondary or third growth forest and is not of adequate size to provide logjam stability or influence channel morphology.

Field observations confirm many of the findings in the Middle Fork Habitat Assessment (LNRD 2011), with most stable LWD in the sub-reaches downstream of the Mosquito Lake Road Bridge. This is attributed to two primary drivers, 1) there is a decrease in channel gradient downstream of the Bridge, reducing the transport capacity of the river to mobilize LWD, and 2) the floodplains and islands adjacent to the active channel that are prone to bank erosion have mature second growth and riparian forests. These characteristics create a sub-reach of the river where there is abundant LWD transported from upstream, and where lateral erosion recruits large key pieces. These larger key pieces rack the mobile LWD from upstream into stable logjams that provide functional in-stream habitat. Downstream of this sub-reach, most of the LWD observed were smaller and not engaged with the low flow channel, residing on gravel bars above the low-flow channel, reducing their habitat function. Because the floodplain forests are less mature downstream, few key logs are recruited into the channel during bank erosion, and when they are present the river tends to migrate away from the larger key logs through more easily erodible bars.

As part of this project LNRD and NSEA further evaluated LWD accumulations to determine whether existing accumulations would offer an analog to develop ELJ structure designs within Middle Fork. To begin this assessment, field locations of existing wood accumulations were identified by NSEA staff using GPS. Following this effort, LNRD staff reviewed historical aerial photographs to determine the relative age 46 LWD accumulations within the lower Middle Fork. The age of LWD accumulations ranged from a maximum of 28-years to a minimum of 1-year. Observations from the historical review indicate that stability or persistence of LWD accumulations was primarily dependent of the degree of engagement with the main channel and channel migration (i.e. LWD accumulations in direct contact with the main channel were vulnerable to scour and mobilization, decreasing their persistence) (Lummi Natural Resources, 2013). Following the desktop review NSD further evaluated the 10 oldest LWD accumulations during our field reconnaissance. Observations from this effort indicated that the majority of the persistent LWD accumulations were not significantly affecting geomorphic processes, habitat conditions within the main channel, and did not offer a consistent analog to develop ELJ designs. LWD accumulations observed generally did have at least one or multiple key pieces but were isolated from the main channel on intermediate floodplain terraces (due to incision), high on braid bars, a significant distance from the main channel (due to channel migration) and did not share a similar geometric orientation. Further, many LWD accumulations appeared susceptible to scour if the main channel were to migrate back towards their location. Observed channel migration trends away from natural LWD accumulations do offer insights to conceptual designs and suggest that ELJs should be located across the entire active channel width at a given river mile to ensure a high likelihood of stable LWD with the main channel as it continues to migrate across the active channel.

One exception to these observations was a large meander type logjam observed in the right bank channel near RM 4.4. This meander jam formed along a sharp bend to right and was supported by mature second growth forest and included a significant pool area upstream of the jam and a side channel exiting from behind. The primary supporting trees for this logjam were 3- to 5-ft in diameter and 150- to 200-ft tall and acted as stable vertical members that trapped mobile wood as flow moved through the forest at high stage flows. This process and performance suggests that incorporating stable vertical members into ELJs designs will improve ELJ stability and allowing high stage flows to flow through the stable vertical members may improve the ability of ELJs to trap mobile wood moving through the project reach.

Overall, LWD loading in the Middle Fork is high, due in large part to channel instability and recruitment of natural LWD. However, large key pieces needed for establishment of stable persistent logjams that can provide functional habitat over the long-term are few. Where large key logs are present they form stable logjams that provide in-stream habitat. Tree size required to classify as a stable key piece was evaluated based on established hydraulic relationships (Abbe and Montgomery 2003), and undisturbed natural reference streams (Fox and Bolton 2007). Based on the bankfull hydraulic conditions (see hydraulic section below), key logs would be classified as larger than 2.8-ft DBH and 75-ft long (with at least 3.5-ft rootwad) (460 cubic ft volume) (based on Abbe and Montgomery 2003). This is larger than the minimum key piece volume of 380 cubic ft calculated using Fox and Bolton (2007). Due to the disturbance in the watershed resulting in a lack of key logs and logjams, the calculated key log size using Abbe and Montgomery (2003) is recommended for stable log dimensions in the Middle Fork.

HYDROLOGY

NSD conducted a hydrologic analysis of the Middle Fork to determine appropriate stream flow values for use as part of hydraulic analysis necessary for habitat enhancement project design. Flood events that are expected to be equaled or exceeded once on average during any 1.01-, 2-, 10-, and 100--year period (recurrence interval) have a special significance for river design projects. These events are commonly referred to as the 1-, 2-, 10-, and 100-year floods. Recurrence intervals represent a long term, average period between floods of a specific magnitude. However, it is important to note that autocorrelation within hydrologic records suggests that low-frequency, or rare floods, could occur at shorter intervals or even within the same year, rather than on a predictable cycle as may be suggested by average values. For habitat enhancement project design purposes, the primary recurrence intervals of interest are the 1-, 2- and 10-year flows due to their influence on habitat and geomorphic conditions.

PEAK FLOWS

The United State Geological Survey (USGS) maintains an active streamflow gauge 12208000 upstream of the project reach near Mosquito Lake Rd. Bridge (N 48°46'46" W 122°06'19"). Operation of USGS gauge number 12208000 was initiated in 1920 but the gauge was inactive between 1921-1933, 1935-1964, and 1978-1992. The 35 years of recorded discharge provide estimates of peak flows for the Middle Fork Nooksack River, beginning in 1920. The top ten peak flows from this gauge are shown below in Table 1. Peak flows for the full period of record are included in Figure 14.

TABLE 1 – TOP TEN PEAK FLOWS

RANK	DATE	FLOW (CFS)*
1	11/6/2006	13700
2	12/3/1975	13100
3	11/24/2004	12500
4	1/17/2011	12200
5	1/30/1971	12100

RANK	DATE	FLOW (CFS)*
6	10/17/2009	12000
7	10/17/2003	11800
8	1/8/2009	10700
9	11/23/2011	8790
10	3/5/1972	8650

* At gauge location

Peak discharge estimates for the combined gauge records were evaluated utilizing a Log Pearson Type III and following using USGS Bulletin #17B procedures (USGS, 1982). Following recommendations by Knowles and Sumioka (2001) this analysis was scaled to the project reach Results from the peak flow and exceedance flow analysis are shown below in Table 2.

Seven of the highest discharges for the Middle Fork have occurred within the past 20-years and have generally occurred during the rainfall-driven portion of the annual hydrograph (October through January). Regional studies support the case that the magnitude and frequency of peak flows are likely to increase in Western Washington as a result of the warming climate (e.g., Mote 2006; Hamlet and Lettenmaier 2007; Abbe et al. 2008; Mote et al. 2008, Lee and Hamlet 2011; Neiman et al. 2011). If this hydrologic trend persists as indicated by modeling predictions, the geomorphic conditions within the project area should be expected to change as the channel adjusts to higher volumes of water being conveyed by the channel.

TABLE 2 – PEAK FLOWS

RECURRENCE INTERVAL (YEARS)	GAUGE LOCATION* (CFS)	PROJECT REACH** (CFS)
1	2200	2700
2	6300	7600
5	9400	11300
10	11600	13900
25	14600	17500
50	16900	20300
100	19400	23300

** Estimated peak flows in the Middle Fork Nooksack based on gauge 12208000 records*

*** Estimated peak flows for MFN project reach based upon basin scaling methods from Knowles and Sumioka (2001)*

HYDRAULIC ANALYSIS

The primary objective of NSD's hydraulic analysis was to estimate hydraulic parameters to characterize current riverine conditions and assist in the design of stable wood structures within the project reach. Hydraulic models were created representative of existing conditions using the Hydronia's RiverFLO-2D v3.1 and Aquaveo SMS v11.1 computer software. RiverFLO-2D is a two-dimensional finite element computer model that provides depth averaged hydraulic parameters at nodes within a triangular model mesh domain. RiverFLO-2d determines depth averaged hydraulic parameters by solving the shallow water equations resulting from the integration of the Navier-Stokes equation. SMS is a GIS based program that creates the triangular model mesh, model input files, and displays model results. The following sections provide more in-depth information on specific components of our hydraulic analysis, data development, and results.

EXISTING CONDITIONS MODEL

The existing condition hydraulic analysis was completed to inform the understanding of current hydraulic and geomorphic processes within the project area and to compare results with proposed condition modeling, completed in future phases, to evaluate the effects of proposed restoration elements. The existing hydraulic analysis was conducted for the 1-, 10-, and 100-yr peak flow discharges. Model runs were performed in a steady state (discharge does not vary with time) and non-deformable bed (no adjustments for scour, sediment transport and deposition).

Model Topography

All hydraulic models utilized 2011 LiDAR data acquired from the Puget Sound LiDAR Consortium to represent channel and floodplain topography. The horizontal and vertical datum of all data utilized and referenced in the report is Washington State Plane Coordinates North Zone NAD83 feet and NAVD 88-feet, respectively. Review of 2011 LiDAR indicates the streamflow of the Middle Fork at the time of the LiDAR acquisition (April 22, 2011) was 220-cfs. Due to the limited light penetrating abilities of LiDAR equipment, channel topography utilizing only LiDAR is representative of the water surface at the time of LiDAR acquisition, not the channel bottom. Review of the 2011 LiDAR data indicates the channel bottom topography is not well represented but the majority of out of water areas (gravel bars and floodplain) is representative of current conditions. If model runs of flows lower than the time of survey (220cfs) are requested in the future phases of this project, we would recommend channel survey be acquired at key locations to increase the accuracy of the model results.

Mesh

A mesh can be conceptualized as a wireframe and is a key component to any 2D hydraulic model. A mesh is composed of nodes and elements that are coded with elevation and roughness values needed to run the computational routine. RiverFlo-2D utilizes a tri-angular mesh to solve for volume conservation and momentum in the x and y directions. For this project the model mesh utilized 213,800 triangular elements and 108,000 nodes.

Roughness

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against movement of water. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Common factors that affect roughness values include: channel sediment size, gradation, and shape; channel shape, channel meandering, both bank and floodplain vegetation, obstructions to flow, flow depth, and flow rate. Manning's n values for this project were set for different roughness types using recent aerial photographs and in accordance with standard hydraulic reference manuals (Chow, 1959; Barnes, 1967; Hicks and Mason, 1998). Model roughness values are shown in Table 3.

TABLE 3 – MODEL ROUGHNESS VALUES

ROUGHNESS TYPES	MANNNG'S N VALUE
Channel_main	0.038
Channel_side	0.046
Gravel bar	0.048
Gravel bar_vegetated	0.07
Logjam	0.15
Pasture/Clearing	0.05
Road_gravel	0.035
Road_paved	0.016
Forest (conifer, deciduous, mixed, dead, clear-cut)	0.12

Boundary Conditions

All hydraulic models require the user to input a known boundary condition at the upstream and downstream extents to begin the computational routine. The upstream boundary condition for all model runs was set to the corresponding peak flow rate minus the flow rate at the time of LiDAR flight (220cfs). Peak flow rates were reduced to account for channel topography that is not accounted for in the LiDAR (i.e. the channel is artificially high). Reducing the model flows in this fashion will result in more accurate model results of the water surface elevations and flow inundation, a key project metric, within the model extents. The downstream boundary conditions for all model runs were set to the corresponding normal depth water surface elevation at the boundary location. The normal depth water surface elevation was determined by solving for normal depth at a cross section, located at the downstream mesh boundary, given the average channel gradient through the project reach of 0.01-ft/ft and manning's n values described above. Model boundary condition values are shown in Table 4.

TABLE 4 – MODEL BOUNDARY CONDITIONS

RECURRENCE INTERVAL (YEARS)	PEAK DISCHARGE (CFS)	MODEL DISCHARGE (CFS)	MODEL DOWNSTREAM WATER ELEVATION (FT)
1.01	2,700	2,480	292.5
10	13,900	13,680	294.4
100	23,300	23,080	295.1

HYDRAULIC ANALYSIS RESULTS

EXISTING CONDITIONS

The results from the EC model runs are shown in Appendix A attached to this report with key observations of model results described below;

- Geologic conditions within the sub-reaches (described above) significantly affect the hydraulics of the lower Middle Fork during peak flow events. Major differences in riverine hydraulics are dependent on the level of confinement created by the underlying geologic conditions.

  Sub-reaches that are confined include RM 0.75-1, 1.25-1.75, 3-3.25, and above RM5.0. In these sub-reaches hydraulic forces can be characterized as severe with deeper flow depths and faster flow velocities. Average ranges for pertinent hydraulic parameters in confined reaches are shown below;

FLOOD INTERVAL (YRS)	DEPTH/VELOCITY
1	4- to 5-ft / 6- 10-ft/s
10	8- to10-ft/ 8- 12-ft/s
100	8- to14-ft / 10- 12-ft/s

  Sub-reaches that are unconfined include RM 0-0.75, 1.0-1.25, 1.75-3.0, and 3.25-5.0. In these sub-reaches hydraulic forces can be characterized as moderate with shallower flow depths and slower flow velocities than in the confined reaches. Average ranges for pertinent hydraulic parameters in unconfined reaches are shown below;

FLOOD INTERVAL (YRS)	DEPTH/VELOCITY
1	2- to 4-ft/ 3- to 7-ft/s
10	4- to 8-ft/ 4- to 8-ft/s
100	5- to 9-ft/ 7- to 9-ft/s

- The degree that underlying geologic conditions affect riverine hydraulic conditions is dependent on the magnitude of the peak flow event. For instance, during the 100-year peak flow the effects are pronounced due to the degree of constriction in confined sub-reaches relative to the unconfined flow width and during the 1-year peak flow the effects are less due to the smaller degree of constriction.

- Riverine hydraulics at RM 4.8 can be characterized as serve due to a combined effect from the constriction caused by the Mosquito Lake Road bridge and roadway embankment and flow exiting the steep and bedrock confined canyon upstream of RM 5.0.

- Flow begins to enter the right bank split channel (Porter Creek side-channel) at RM 4.8 at approximately 1,600-cfs based upon field observations, which is approximately 60% of the 1-year peak flow. The proportion of flow in each of the split channels from the hydraulic model is as follows;

FLOOD INTERVAL (YRS)	LEFT CHANNEL (CFS)	LEFT CHANNEL (%)	RIGHT CHANNEL (CFS)	RIGHT CHANNEL (%)
1	2,450	99	30	1
10	9,280	68	4,400	32
100	14,880	64	8,200	36

- The debris jam that formed at RM 4.3 following the channel avulsion at RM 4.8 is not inundated during the 1-year flow, and the old channel just upstream of the jam (where significant sedimentation was observed) is not inundated during the 100-year flow. This suggests that the left channel has incised since the channel avulsion.

- Prominent side channels through the right bank floodplain at RM 2.4 and 3,500-ft in length are activated at the 1-year peak flow. Flow depths and velocities range between 3- to 5-ft and 1- to 3-ft/s in these channels, respectively.

- A side channel through the left bank floodplain at RM 2.5 and 1,400- feet in length is activated at the 1-year peak flow. Flow depths and velocities range between 1- to 3-ft and 0.5- to 1-ft/s in these channels, respectively.

SUMMARY AND RECOMENDATIONS

Our geomorphic assessment demonstrates that geologic controls and historic disturbances play a significant role on aquatic habitat quality, abundance and distribution within the Middle Fork. It is clear that the cumulative effects of natural geologic constrictions and human disturbance have affected aquatic habitat conditions, with human disturbance a likely contributor to channel incision. Given the watershed and geomorphic conditions, this reach of the river is naturally susceptible to significant changes as variations in LWD loading, sediment supply and flows. The loss of functional and stable wood (trees greater than 4-ft in diameter and over 100-ft in length) could easily explain the historic trend in channel incision, channel instability, and lack of pools. The original forest had trees that would have obstructed the entire river channel when they fell that would easily have formed stable logjams that overtime would have created base level control and reduced the rate and magnitude of fluvial changes. Wolff (1916) described how the immense timber in the larger White River (King County) controlled the course of the river and patterns of sediment deposition. With the loss of stable wood, the river has increased its streamflow energy and sediment transport capacity resulting in scour that has gradually lowered the channel and increased channel migration. When combined with shorter channel lengths resulting from on-going channel migration and avulsions, incision has been further exacerbated, creating a negative feedback loop. Numerous large stable wood placements in the form of engineered logjams (ELJs) are critical to reverse this feedback loop to slow incision and habitat degradation. Without countermeasures, incision will continue, further simplifying and isolating habitat features. Disconnection of off-channel habitats (floodplains, floodplain side channels, and tributaries) has already been documents, and would be anticipated to worsen should incision continue. With evidence that peak flows may be increasing as a result of the warming climate, it is even more important to aggressively reload the Middle Fork with stable wood and accelerate reforestation of riparian and floodplain areas. To ensure ELJ placements are engaged a high percentage of the time, placements should be made across the active channel width whenever possible. Observations of constructed LWD placements and persistent natural LWD accumulations within the Middle Fork suggest the stable LWD is very effective at creating flow obstructions leading to sediment deposition and channel migration away for the stable LWD locations. To combat this trend, ELJ placements that are across the width of the active channel for a given river mile will ensure that as the low flow channel migrates across the active channel, it will be engaged with stable LWD at one or multiple locations.

Recommendations for ELJ placement objectives within the project area include;

- Create stable pool habitat
- Split high stage flows to cause sediment sorting and sediment deposition (sorting of spawning sized gravels)
- Promote forested island development (creation of stable hard point limiting floodplain disturbance in lee of structure)

- Increase floodplain and side channel connectivity by local flow deflection and reach-wide increases in water surface elevations (from increased in-stream roughness)
- Trap mobile large wood to increase resonance time (stability) of LWD within reach
- Dissipate high streamflow energies through adding roughness and disrupting flow patterns to improve long-term channel stability

Our summary and recommendations specific to each sub-reach is as follows,

Sub Reach 1 (RM 0-1.0)

Restoration in this furthest downstream reach is focused on the current active channel, to promote stable island formation, increase side channel and floodplain connectivity, and creation of stable habitat features. A key result of these restoration actions will be a significantly higher roughness in the current active channel, thus increasing potential for channel migration through a more preferential (less resistant, lower roughness) flow path. Due to this potential for channel migration within this sub-reach, adaptive management is recommended to monitor habitat conditions.

Primary restoration objectives;

1. Promote forested island development
2. Create pool habitat
3. Split high stage flows to cause sediment sorting and sediment deposition
4. Trap mobile large wood. Natural deposition zone before confluence with the North Fork.

Priority – Moderate

Feasibility – Moderate to poor. Left bank high and steep with private property along both banks. Most likely access from right bank private property.

Sub Reach 2 (RM 1.0-1.5)

The primary objective within this sub-reach is to improve channel stability in this over-widened reach. Stability will be achieved through creation of hard points (ELJs) in the active channel that will dissipate streamflow energies and lead to forested island development. Given high streamflow energies and limited access in the reach it was given a low priority.

Primary restoration objectives;

1. Promote forested island development
2. Dissipate high streamflow energies through adding roughness and disrupting flow patterns
3. Create stable pool habitat

Priority – Low

Feasibility – Moderate to poor. Left bank high and steep with private property along both banks. Most likely access from right bank private property.

Sub Reach 3 (RM 1.5-1.7)

This naturally confined sub-reach has likely been a transport reach for LWD historically, as the hydraulic results demonstrate velocities are higher than most other locations along the Middle Fork. To improve the stability of the low-flow channel, ELJs are recommended to provide hard points that will reduce streamflow energies and create stable habitat features. Shear stress partitioning due to higher roughness from the ELJs will also decrease erosive energy. Given high streamflow energies and limited access in the reach it was given a low priority.

Primary restoration objectives;

1. Dissipate high streamflow energies through adding roughness and disrupting flow patterns
2. Create stable pool habitat

Priority – Low

Feasibility – Moderate to poor. Left bank high and steep with private property along both banks. Most likely access from left bank private property.

Sub Reach 4 (RM 1.7-3.3)

Restoration in this dynamic sub-reach is focused on the current active channel to improve stability through creation of stable hard points to trap mobile LWD and promote island formation. Historic and recent incision has led to disconnected floodplains where the active channel once occupied. Strategic ELJ placements will be used to re-engage side channels and elevate water surface elevations over the range of flow conditions to further re-connect these floodplains and their associated habitat benefits. A key result of these restoration actions will be a significantly higher roughness in the current active channel, thus increasing the channel migration through a more preferential flow path. Due to this potential for channel migration within this sub-reach, adaptive management is recommended to monitor habitat conditions.

Primary restoration objectives;

1. Increase floodplain and side channel connectivity. Focus on left bank side channel at RM 2.4 and right bank side channels at RM 2.3.
2. Promote forested island development
3. Create stable pool habitat
4. Trap mobile large wood. Large supply of mobile wood following upstream avulsion and subsequent incision. Additional LWD recruitment following upstream ELJ placements likely

Priority – Moderate to high

Feasibility – Moderate. Private property along right bank with private timber parcels along left bank. Most likely access from right bank private property.

Sub Reach 5 (RM 3.3-3.7)

Because the active (unvegetated) channel has remained relatively stable over time, restoration in sub-reach 5 is focused on creating stable islands within the active channel to improve stability of the low flow channel. The highly dynamic upstream sub-reach 6 is a source of abundant LWD into this sub-reach, and creation of multiple stable hard points in the active channel will increase the residence time of LWD and provide more stable habitat features.

Primary restoration objectives;

1. Promote forested island development
2. Create stable pool habitat
3. Trap mobile large wood. Large supply of mobile wood following upstream avulsion and subsequent incision. Additional LWD recruitment following upstream ELJ placements likely as channel adjusts

Priority – Moderate to high

Feasibility – Good. Land ownership is a mixture of private and DNR timber parcels. Most likely access from Porter Creek side channel access along right bank.

Sub Reach 6 (RM 3.7-5.0)

Due to the documented instability within the sub-reach (multiple channel avulsions and lateral erosion), high value habitat at risk, and large tracts of public land, sub-reach 6 is the highest priority sub-reach. Restoration actions are focused on the current active channel flow path (left channel) and aim to meet the following objectives:

Primary restoration objectives;

1. Increase floodplain and side channel connectivity. Focus on perennial split at RM 4.8 and slowing incision from recent avulsion.
2. Dissipate high streamflow energies through adding roughness and disrupting flow patterns. Focus on reach immediately downstream of Mosquito Lake Road Bridge to RM 4.5.
3. Create stable pool habitat
4. Trap mobile large wood. Large local supply of LWD as channel adjusts to ELJs

Within the larger sub-reach we recommend focusing initial efforts in two areas. The first area is located near RM 4.8 with the intent of increasing the frequency of flow into the right bank channel. Presently, flow enters this channel at and above 1,600-cfs and channel incision in combination with sediment deposition in the right bank channel has the potential to further disconnect this area from the current channel. Increasing the connectivity of the right bank channel offers two primary benefits 1. Reducing stream energies currently eroding into the Peat Bog and Bear Creek tributary channels, 2. Dramatically increasing habitat quantity and quality (a perennial split would double the main channel and edge habitat within this sub-reach). Given the geomorphic conditions at RM 4.8, the channel should be expected to continue dynamic behavior in the future and ELJs placed to increase flow into the right bank channel will also provide bounds on future channel response through the formation of stable hard points. The second area is located at RM 4.3 near the Bear Creek and Peat Bog Creek confluences with the MFN. In 2013 these tributaries had 90% of the observed spawning within the entire lower MFN (Lummi, 2013). Presently, these areas are at risk of being captured by the main channel through channel migration and bank erosion. ELJs in this area would be located to deflect flow away from the Peat Bog and Bear Creek tributary channels and also create/improve habitat through the creation of pools.

Priority –High

Feasibility – Good. Land ownership is a mixture of private and DNR timber parcels. Most likely access from Porter Creek side channel along right bank or Mosquito Lake Road bridge parking area along left bank.

To achieve these objectives we have developed conceptual designs and layouts for ELJ placements within the project area (see Appendix B). ELJ structure types were developed to mimic the size, form, and function of historic stable LWD within the Middle Fork and using observations from persistent LWD accumulations observed during the field reconnaissance. The ELJ structure types developed for this project are as follows;

- TYPE 1 ELJ – Type 1 ELJs are the largest proposed structures with a width and length of 80- and 45-feet, respectively. Type 1 ELJs will mimic the geomorphic, ecologic and hydraulic function once provided by large old growth tress that once lines the banks and were recruited into the channel of the Middle Fork. These structures are intended to force primary pool formation on the upstream end, promote stable forested island formation downstream, increase instream cover, sort spawning sized gravels, and with a sufficient number of structures densely spaced will decrease basal shear stresses reach-wide to promote bed aggradation. Type 1 ELJs will be excavated into the channel bed to protect the structure from scour and will be post supported. Due to the construction cost of this ELJ type, placements were limited to high energy or severe hydraulic locations where a simpler less robust ELJ might become unstable.

- TYPE 2 ELJ – Type 2 ELJs are a medium sized structure with a width and length of 60- and 35-feet, respectively. Type 2 ELJs will provide similar geomorphic, ecologic and hydraulic benefits as the Type 1 structures at a smaller scale and are strategically placed to function with adjacent ELJs to increase habitat benefits while providing cost savings. Type 2 structures will be excavated into the channel bed to protect the structure from scour, post supported, and cost less than Type 1 structures. Due to the construction cost of this ELJ type, placements were limited to high energy or severe hydraulic locations where a simpler less robust ELJ might become unstable.
- TYPE 3 ELJ – Type 3 ELJs are a large structure with a width and length of 75- and 35-feet, respectively. Type 3 ELJs will provide similar geomorphic, ecologic and hydraulic benefits as the Type 1 structures at a much lower cost. The Type 3 ELJ design was partially developed to mimic the vertical members (in the form of mature second growth trees) observed in the persistent LWD accumulation at RM 4.5 in the Porter Creek channel and also on a pile array ELJ developed for the Upper Quinault River (see Figure 15). To reduce construction costs, the Type 3 structure will be excavated a nominal depth into the channel, is post supported, and "seeded" with a small number of key pieces and racking material. To have its intended effect, the Type 3 structure relies on trapping mobile wood moving through project reach to create large stable wood accumulation. Minimizing the excavation depth and number of key pieces results in significant cost savings but also a less robust structure. Type 3 structures are located in sub-reaches that are lower energy or less severe hydraulic locations where natural LWD would be likely to deposit and where the structure is at a lower risk of becoming unstable. Similar low cost structure have been developed and successfully implemented on the Upper Quinault River as shown in Figure 15 and offer a great opportunity to re-introduce stable LWD on a reach scale in the Middle Fork.

LIMITATIONS

We have prepared this report for the Nooksack Salmon Enhancement Association, their authorized agents and regulatory agencies responsible for the Middle Fork Nooksack restoration project. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices for geomorphology and hydraulics in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

We appreciate this opportunity to be of service to the NSEA for this project and look forward to continuing to work with you. Please call if you have any questions regarding this report, or if you need additional information.

Sincerely,

Natural Systems Design, Inc.

R. Leif Embertson, MS, PE, CFM
Senior River Engineer

Tim Abbe, PhD, PEG, PHG
Principle Geomorphologist

Attachments:

FIGURE 1 – Project Reach Map
FIGURE 2 – Historic timber harvest and old growth stumps in the Middle Fork Nooksack
FIGURE 3 – Flow split at RM 4.9 at 1,600 cfs
FIGURE 4 – Channel avulsion between RM 3.9 – 4.8
FIGURE 5 – Geologic Map (entire project reach scale)
FIGURE 6 – Exposed lahar deposit at RM 0.8
FIGURE 7 – REM Map (entire project reach scale)
FIGURE 8 – Historic Active Channels Map (entire project reach scale)
FIGURE 9 – RM 0.4 Section
FIGURE 10 – RM 2.2 Section
FIGURE 11 – RM 3.2 Section
FIGURE 12 – Large debris jam at RM 4.3
FIGURE 13 – LWD Map (entire project reach scale)
FIGURE 14 – Annual peak streamflows Middle Fork Nooksack
FIGURE 15 – Quinault River ELJ structures

Appendix A – Hydraulic model results

Appendix B – Conceptual design drawings

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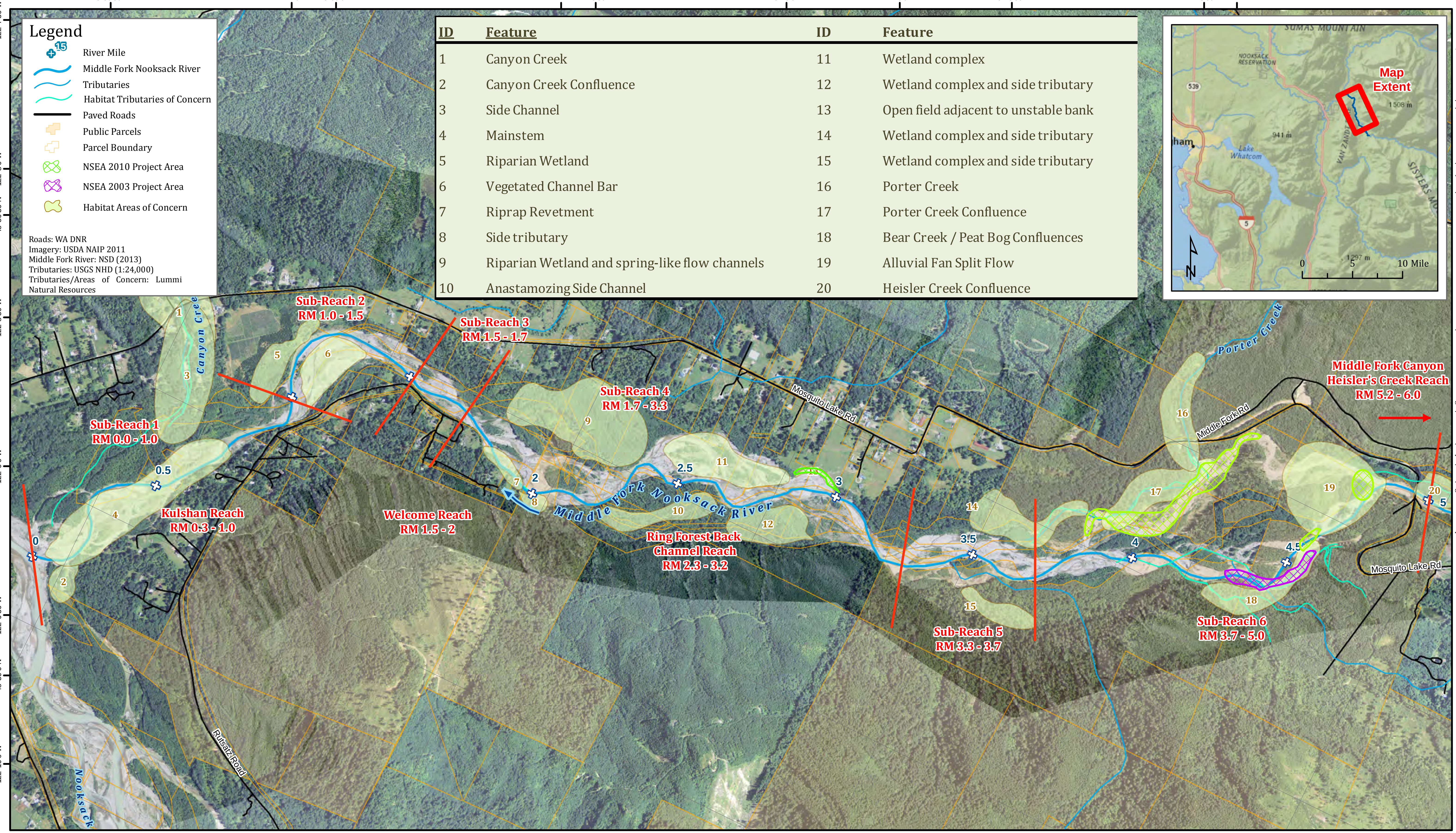

ID	Feature	ID	Feature
1	Canyon Creek	11	Wetland complex
2	Canyon Creek Confluence	12	Wetland complex and side tributary
3	Side Channel	13	Open field adjacent to unstable bank
4	Mainstem	14	Wetland complex and side tributary
5	Riparian Wetland	15	Wetland complex and side tributary
6	Vegetated Channel Bar	16	Porter Creek
7	Riprap Revetment	17	Porter Creek Confluence
8	Side tributary	18	Bear Creek / Peat Bog Confluences
9	Riparian Wetland and spring-like flow channels	19	Alluvial Fan Split Flow
10	Anastamozing Side Channel	20	Heisler Creek Confluence

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0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Middle Fork Nooksack River LWD Preliminary Design

Project Reach Basemap

LiDAR Hillshade from : Watershed Sciences (2011) LiDAR (collected April, 22nd 2011 at 220 cfs)
Aerial Imagery from: USDA National Agriculture Imagery Program 2011
River Miles digitized by NSD based on 2011 low-flow channel
Habitat reach segments from MFN River Habitat Assessment (Lummi Nation, 2011)

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FIGURE 2 – Historic harvest of large diameter timber in the Nooksack basin (Top left, Whatcom County Museum); large stump in Porter Creek channel near RM 4.3 (Top right); LWD at RM 3.5 (Lower left); and old growth stump in right bank floodplain near RM 5 (Lower right)

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FIGURE 3 – Flow split at RM 4.9 at 1,600 cfs.

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FIGURE 4 – Channel Avulsion between RM 3.9 - 4.8; 2005 (left) to 2011 (right).

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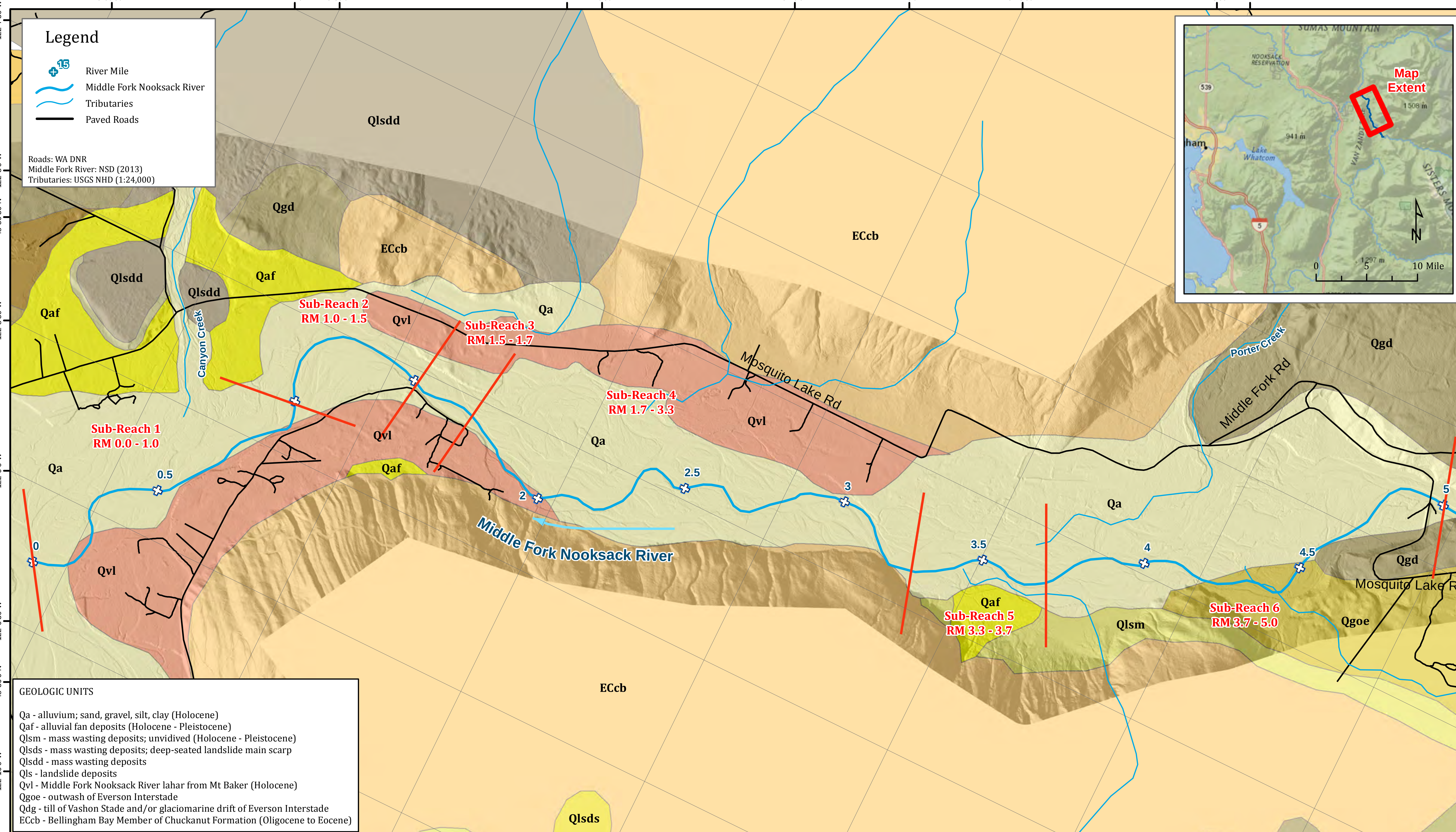

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Middle Fork Nooksack River LWD Preliminary Design

Geologic Map

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

LiDAR Hillshade from : Watershed Sciences (2011) LiDAR (collected April, 22nd 2011 at 220 cfs)
Aerial Imagery from: USDA National Agriculture Imagery Program 2011
River Miles digitized by NSD based on 2011 low-flow channel

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FIGURE 6 – Exposure of resistant lahar deposit along left bank at RM 0.8

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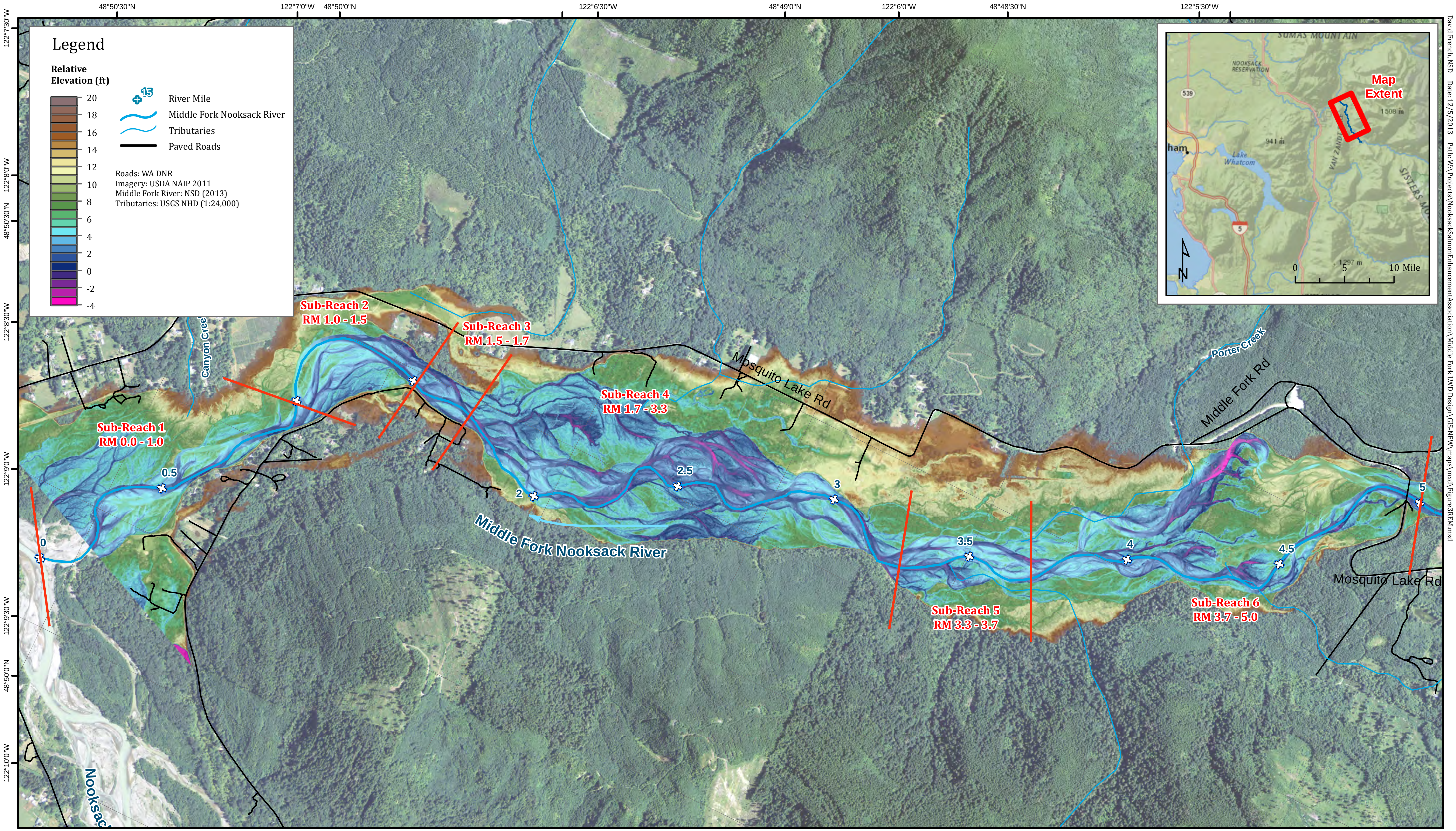


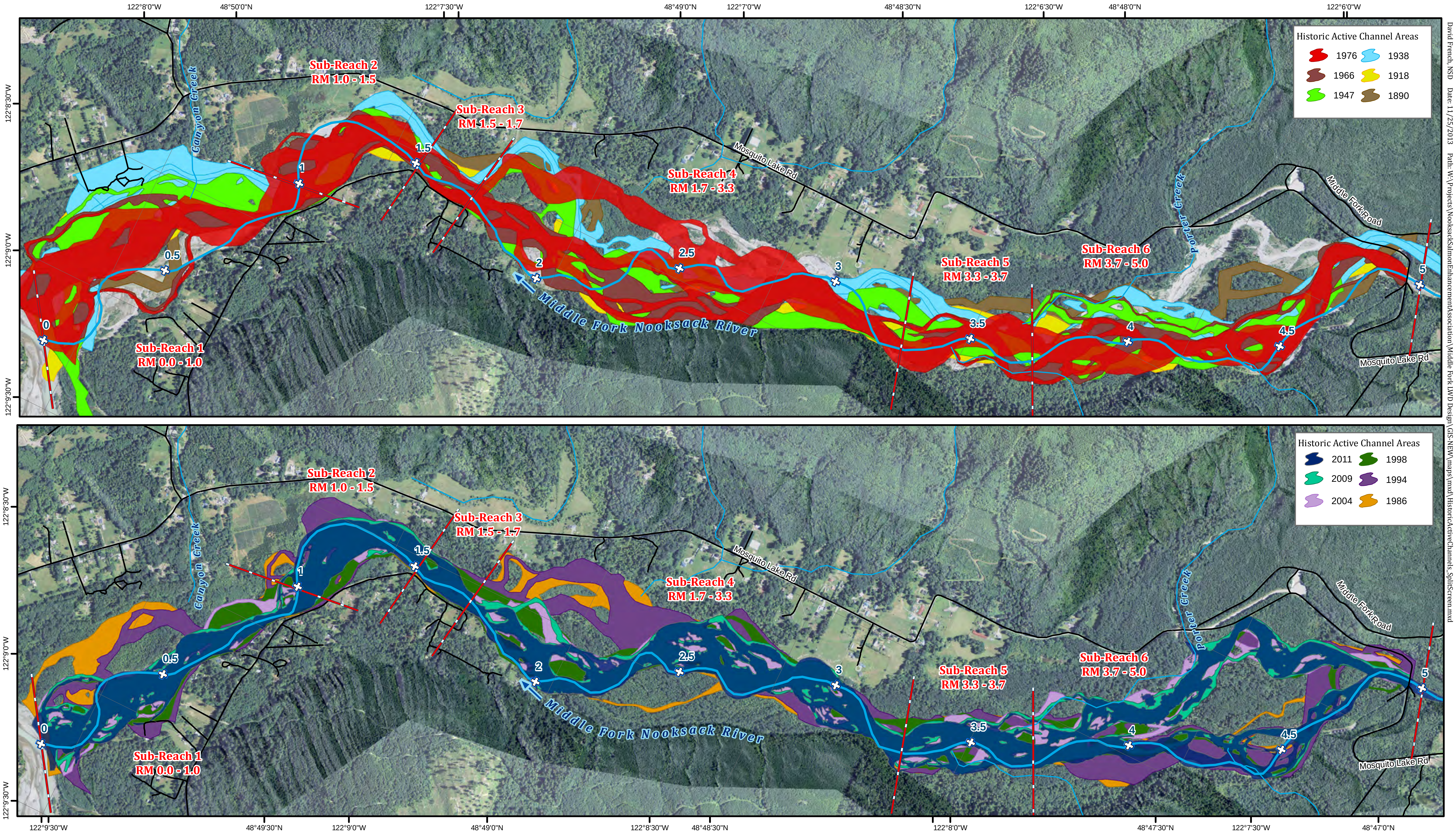
0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

Middle Fork Nooksack River LWD Preliminary Design

Relative Elevation Map

LiDAR Hillshade from : Watershed Sciences (2011) LiDAR (collected April, 22nd 2011 at 220 cfs)
Aerial Imagery from: USDA National Agriculture Imagery Program 2011
River Miles digitized by NSD based on 2011 low-flow channel



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Historic Active Channels

LiDAR Hillshade from : Watershed Sciences (2011) LiDAR (collected April, 22nd 2011 at 220 cfs)
Aerial Imagery from: USDA NAIP 2011
River Miles digitized by NSD based on 2011 low-flow channel
Roads: WA DNR, Imagery: USDA NAIP 2011, Middle Fork River: NSD (2013)
Tributaries: USGS NHD (1:24,000)

15 River Mile
Middle Fork Nooksack River
Tributaries
Roads

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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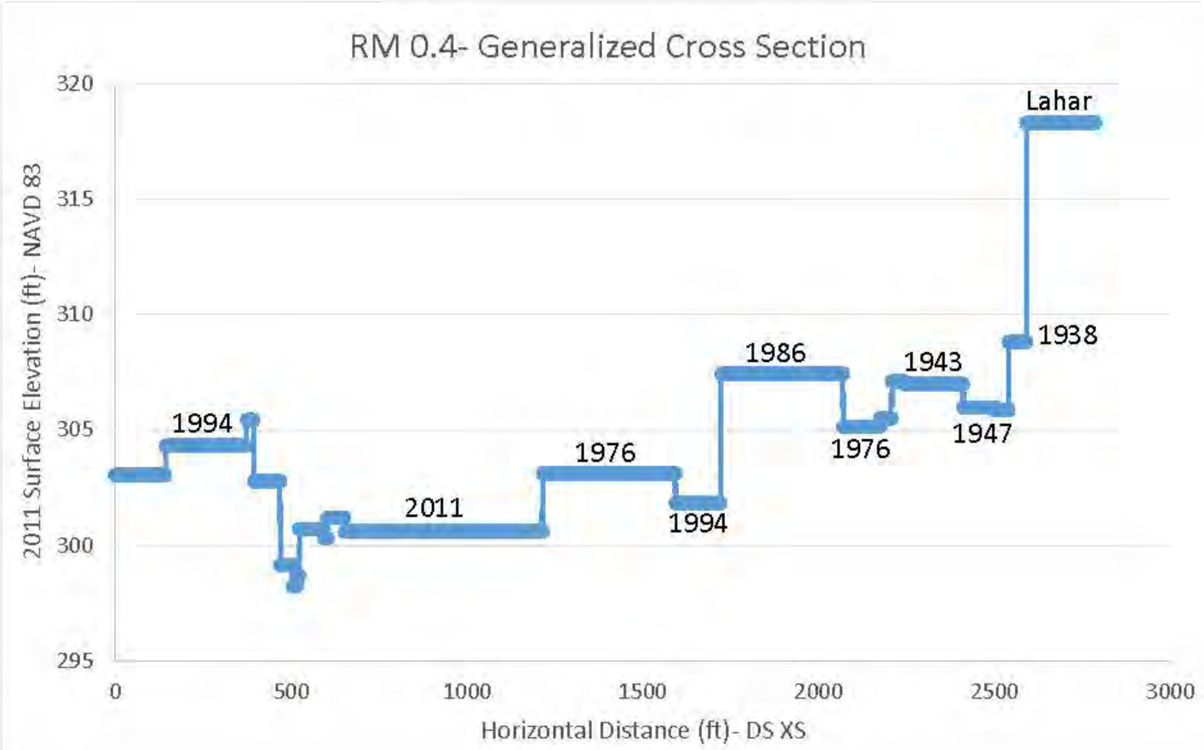

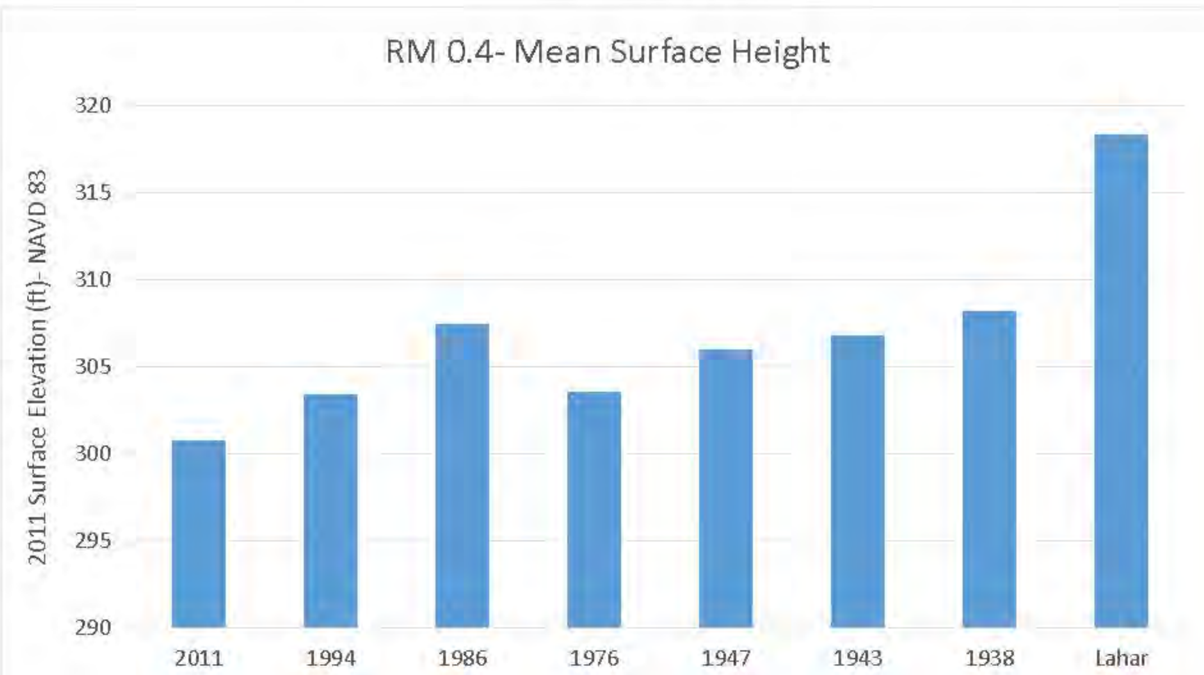

FIGURE 9 – RM 0.4 Section

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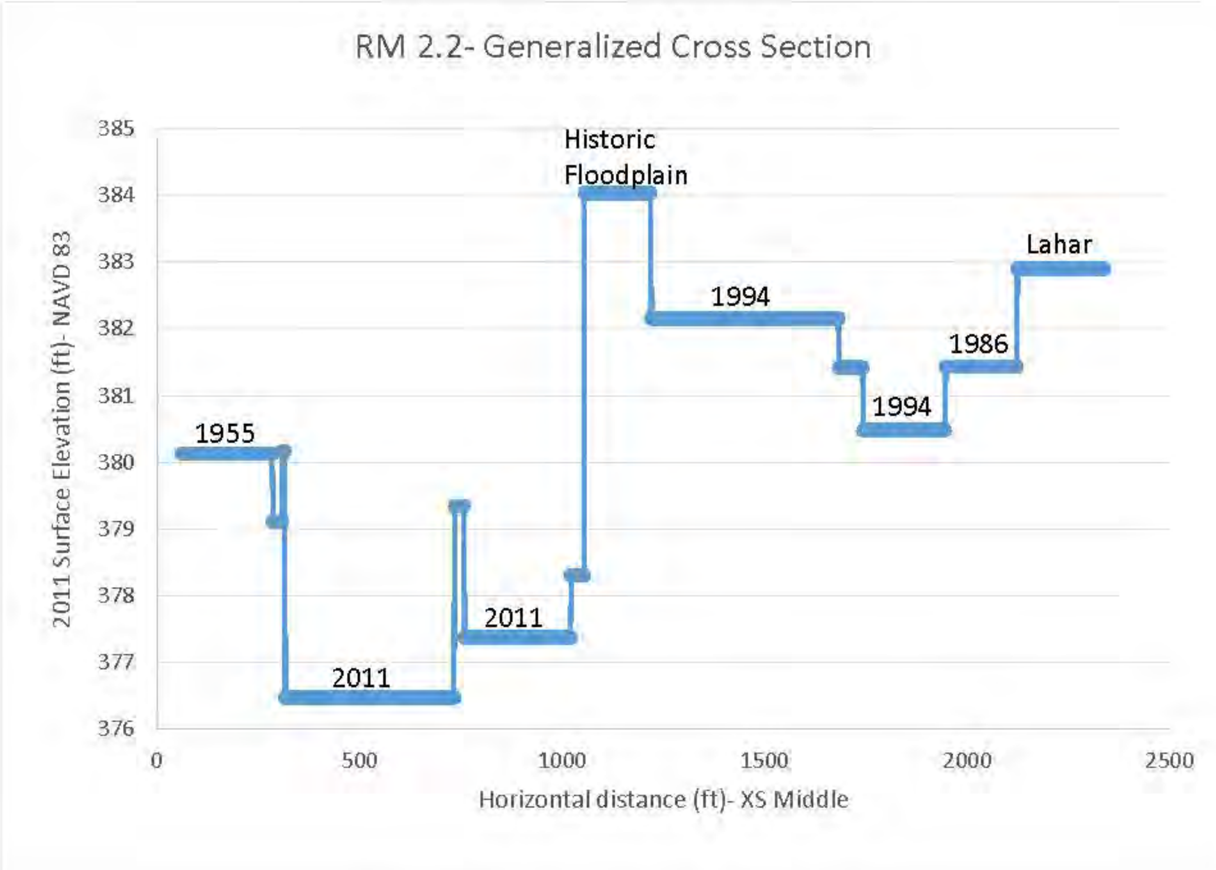

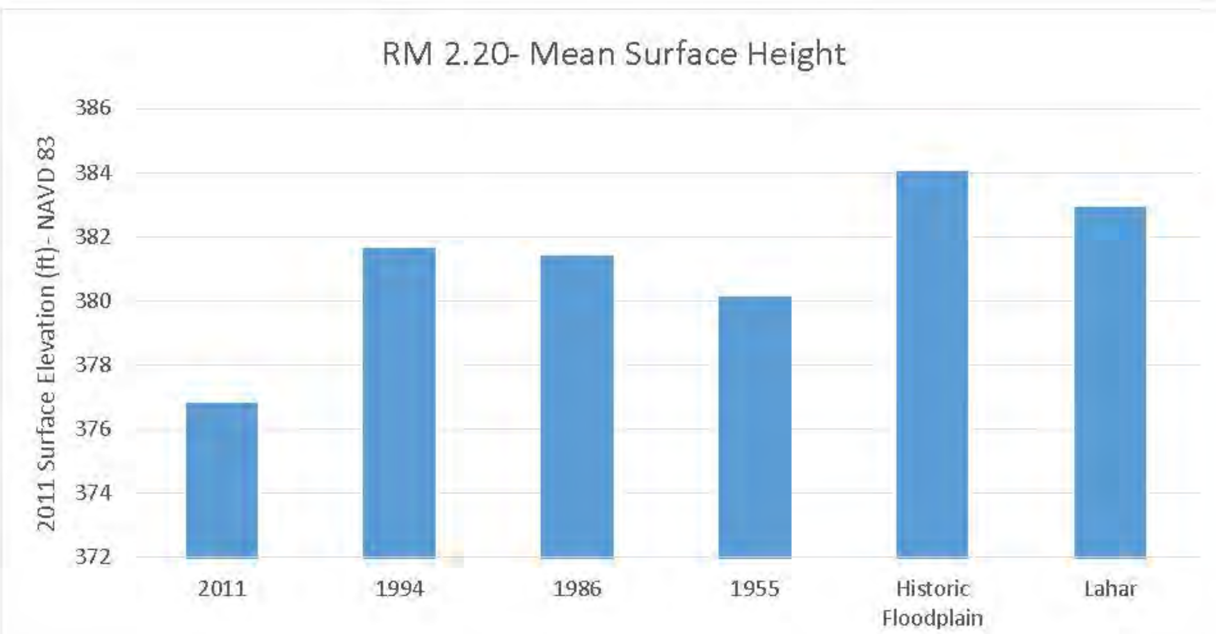

FIGURE 10 – RM 2.2 Section

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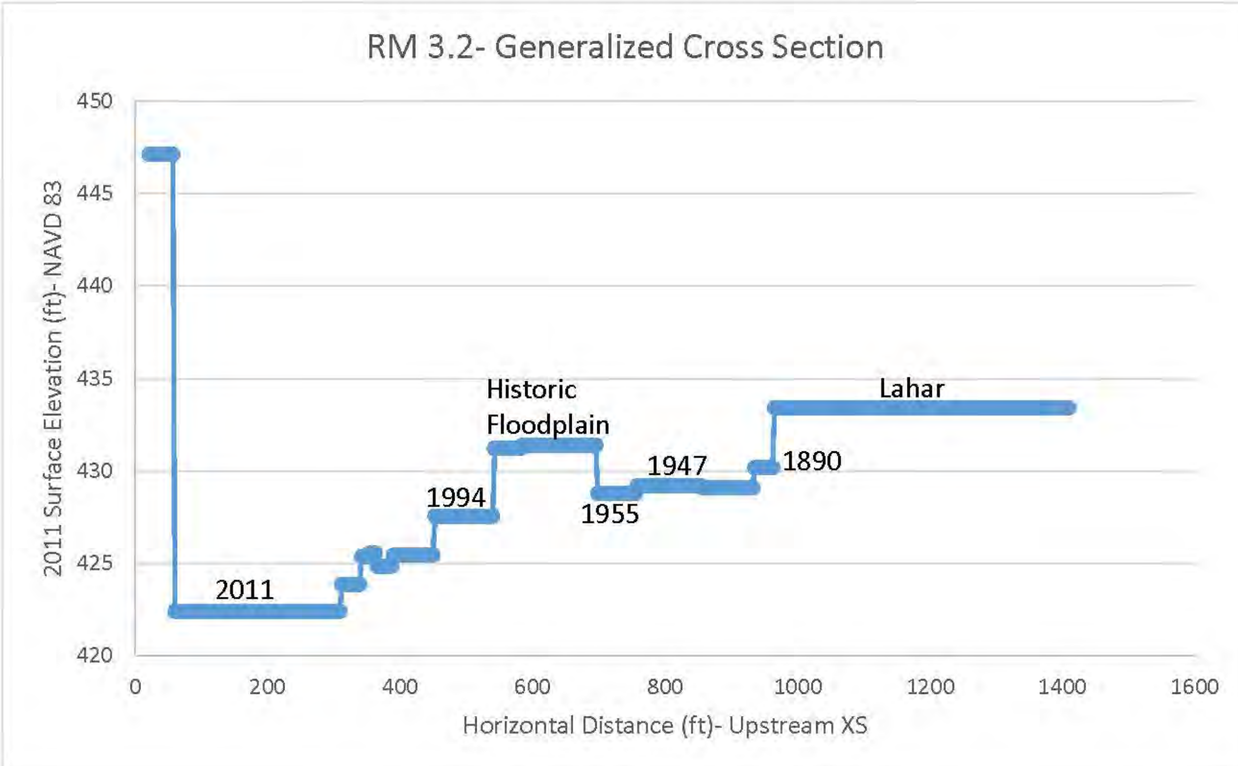

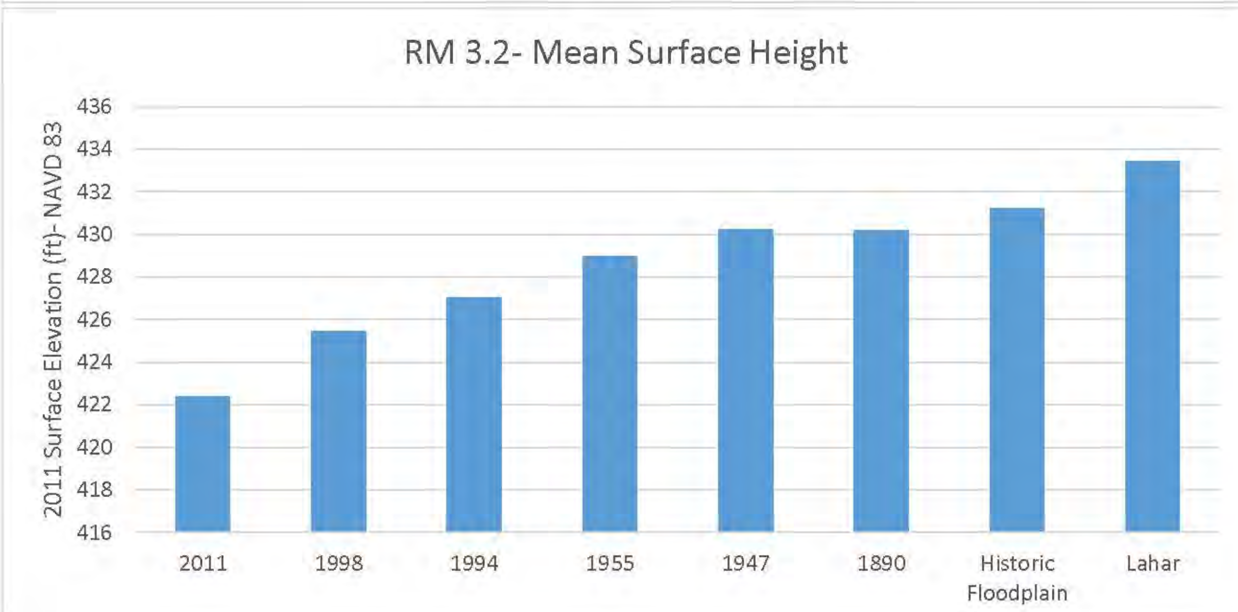

FIGURE 11 – RM 3.2 Section

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FIGURE 12 – Large debris jam near RM 4.3

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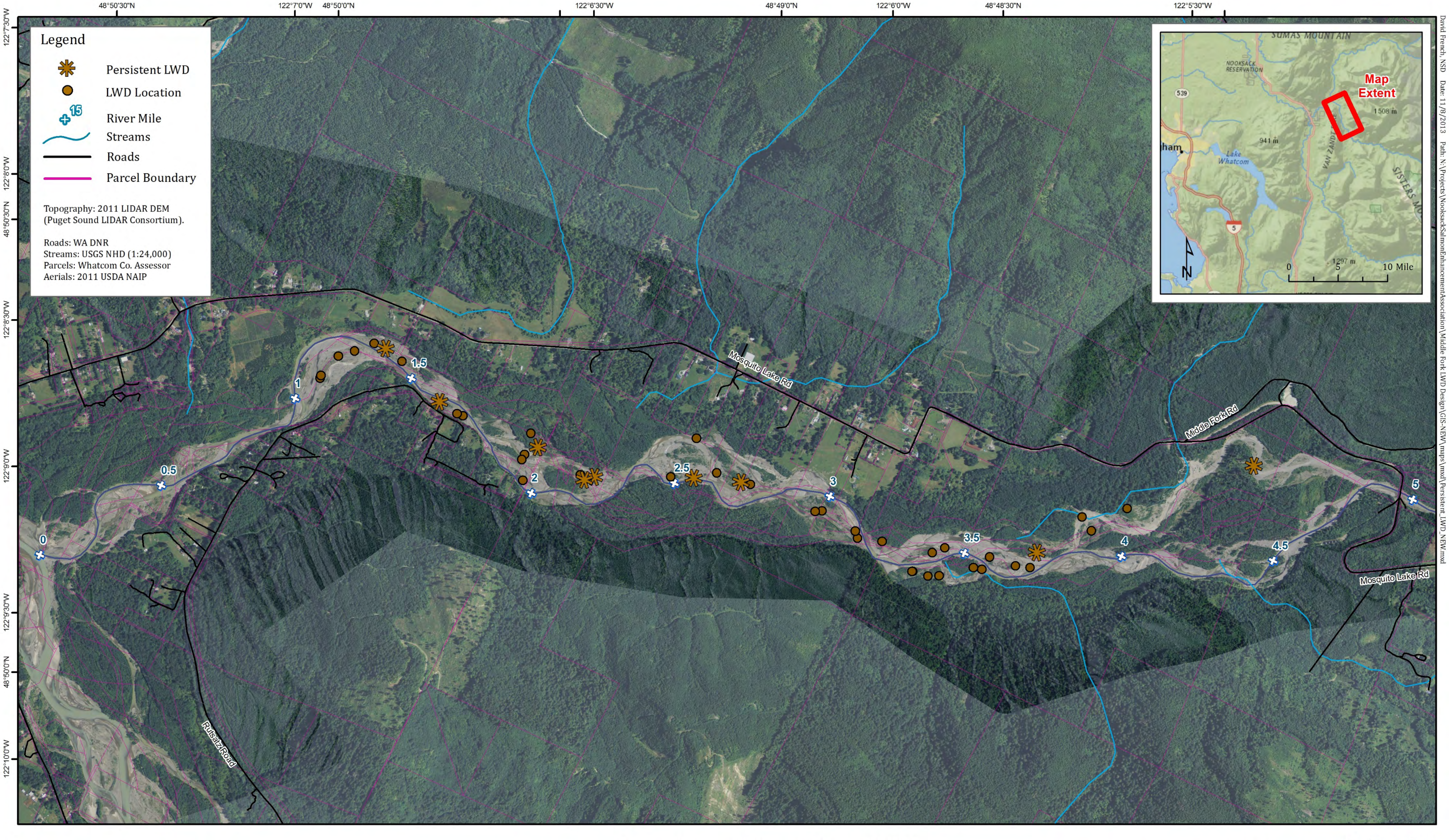

Middle Fork Nooksack River LWD Preliminary Design

Persistent LWD Locations

LWD data from NSEA, 2013

FIGURE 13

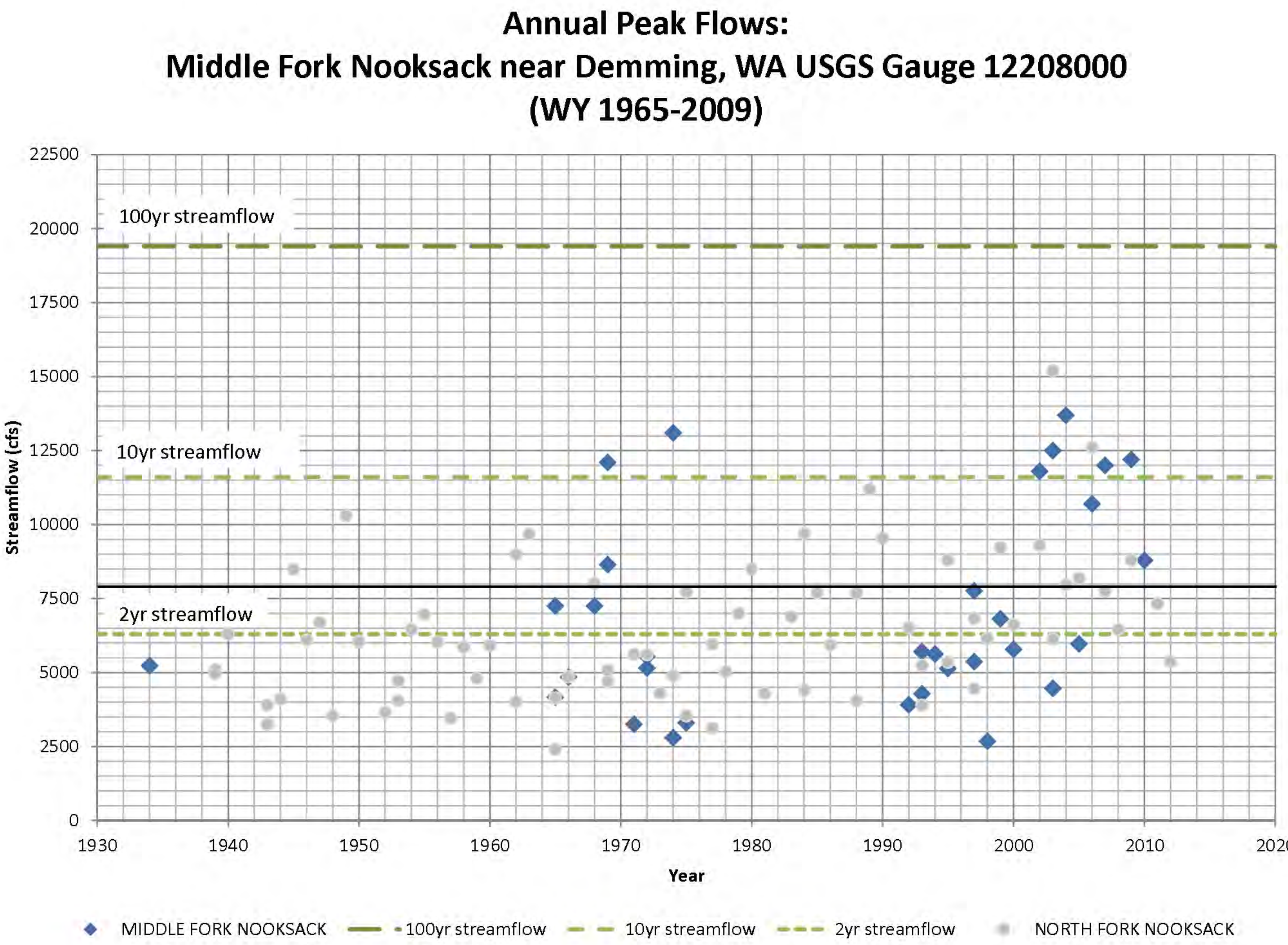

FIGURE 14 – Annual peak streamflows Middle Fork Nooksack

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FIGURE 15 – 2013 Aerial photo (GoogleEarth) of constructed pile array ELJs on the Upper Quinault River basin (Top left); Left bank pile array ELJ constructed in 2012 (Lower left); Center channel pile array ELJ constructed in 2012 with significant newly racked mobile LWD (Lower right)

APPENDIX A

HYDRAULIC

MODEL OUTPUT

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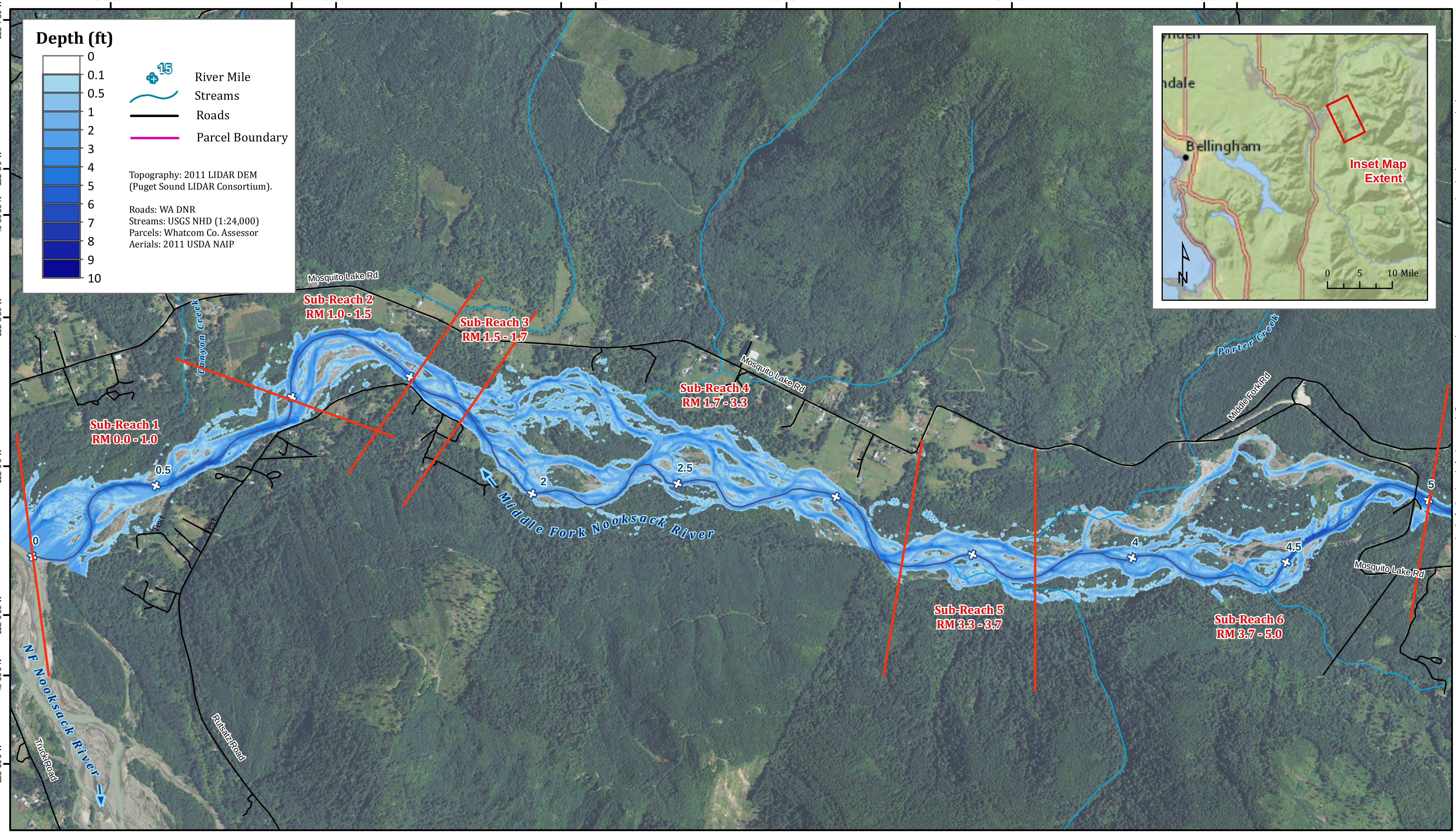

Middle Fork Nooksack River LWD Preliminary Design

1 Year Model Output - Project Area

Existing Conditions- Depth

Hydronia RiverFlo 2D SMS Model Output based on 1 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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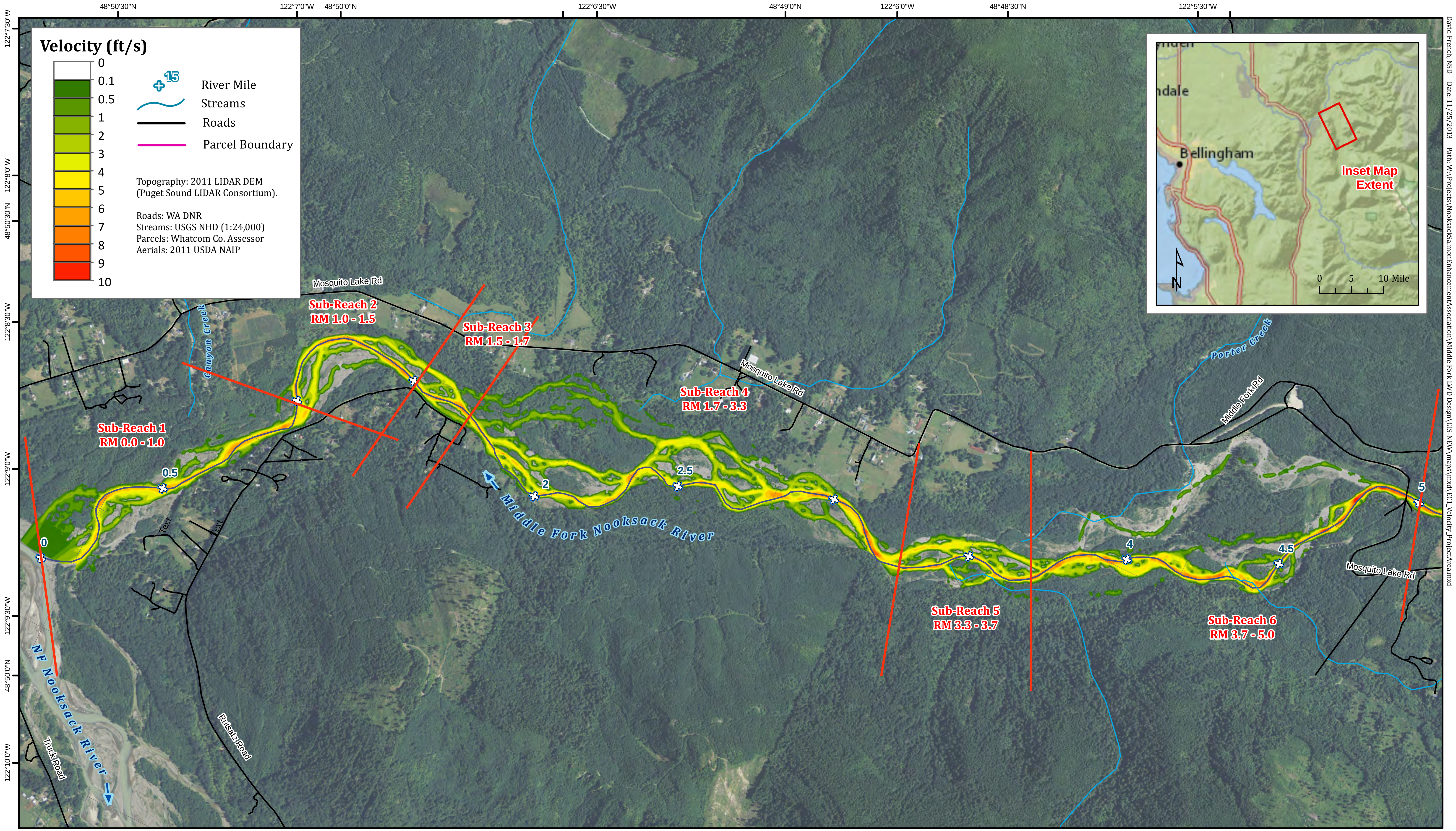

Middle Fork Nooksack River LWD Preliminary Design

1 Year Model Output - Project Area

Existing Conditions- Velocity

Hydronia RiverFlo 2D SMS Model Output based on 1 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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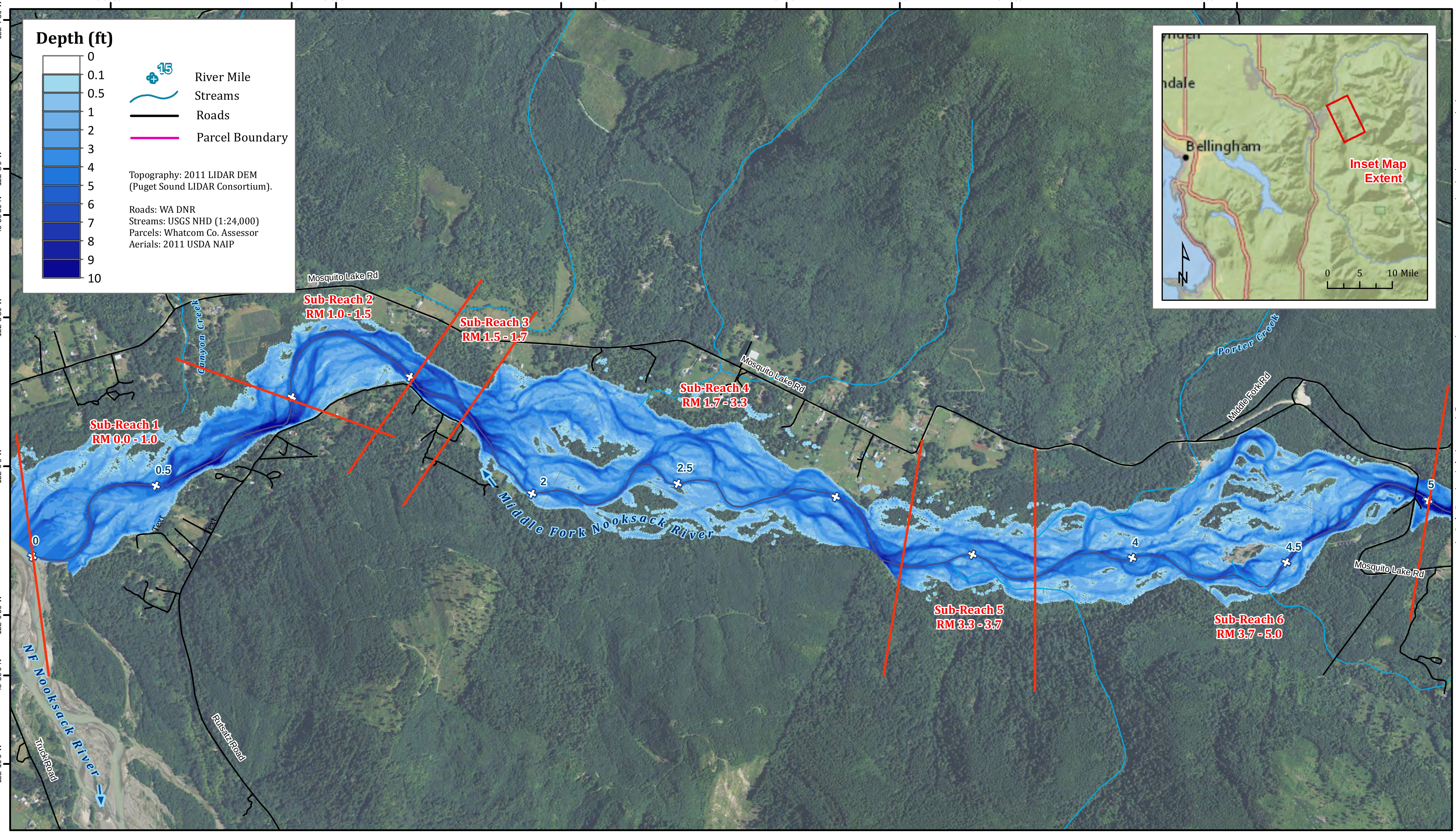

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Middle Fork Nooksack River LWD Preliminary Design

10 Year Model Output - Project Area

Existing Conditions- Depth

Hydronia RiverFlo 2D SMS Model Output based on 10 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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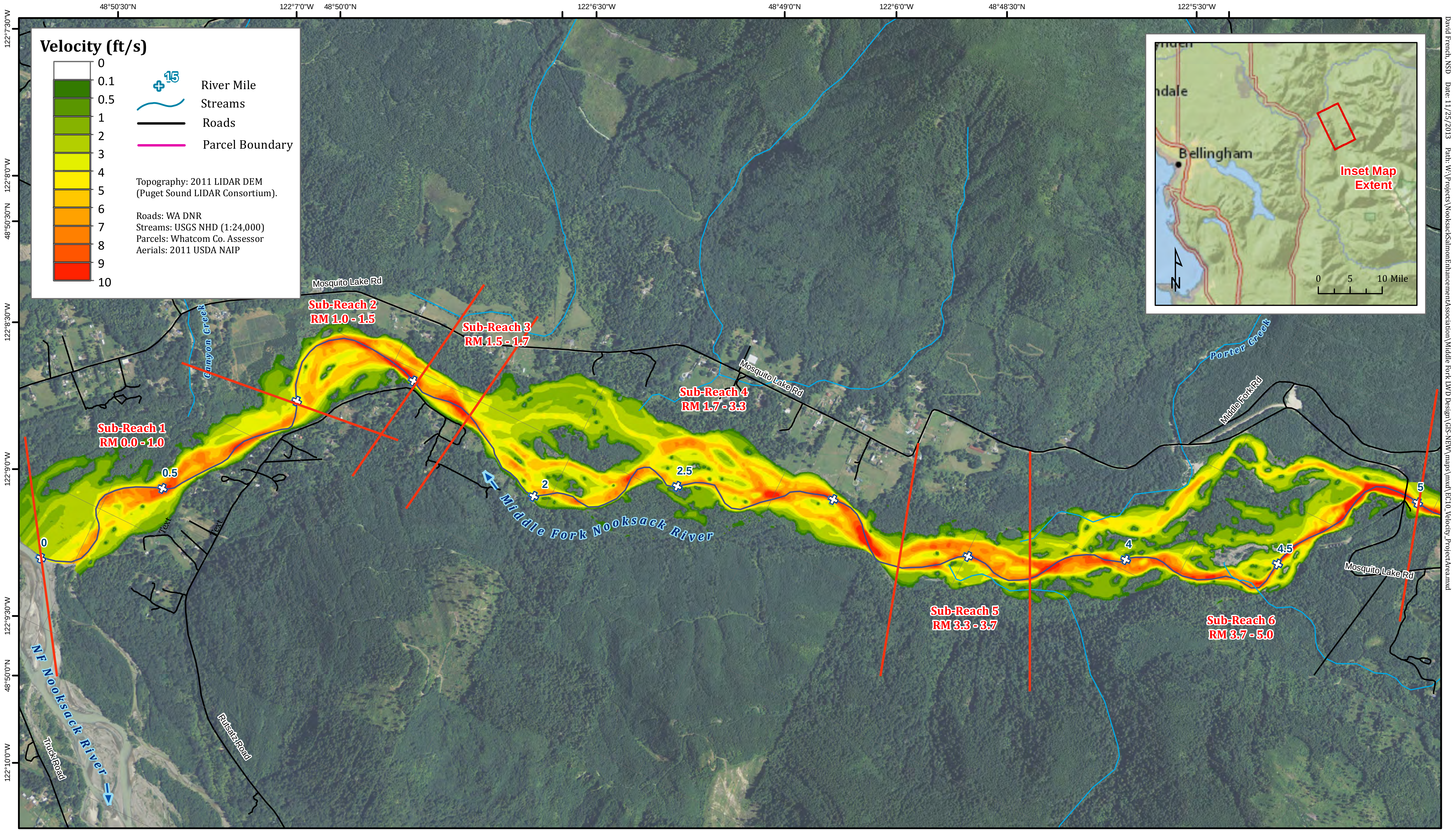

Middle Fork Nooksack River LWD Preliminary Design

10 Year Model Output - Project Area

Existing Conditions- Velocity

Hydronia RiverFlo 2D SMS Model Output based on 10 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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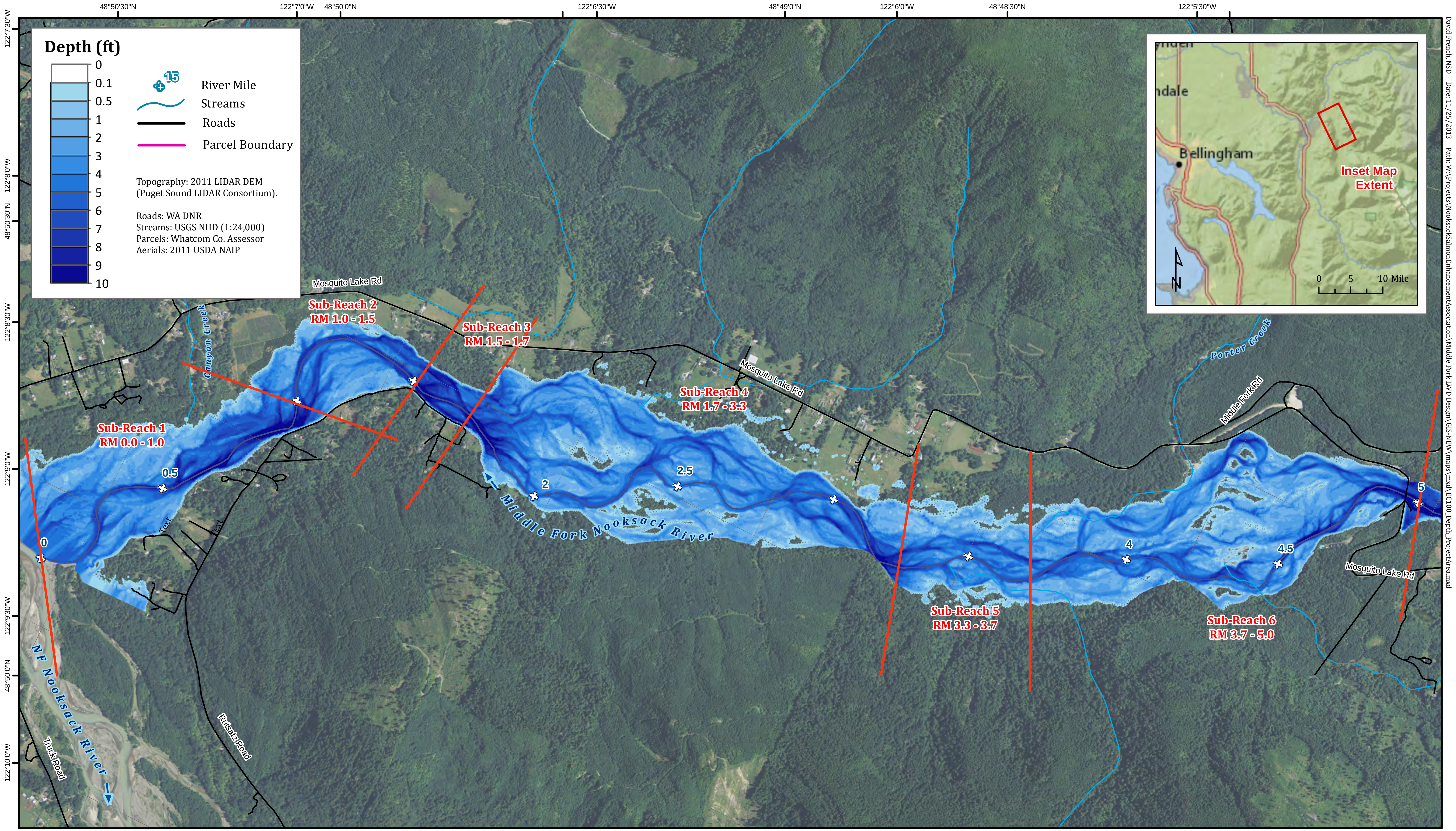

Middle Fork Nooksack River LWD Preliminary Design

100 Year Model Output - Project Area

Existing Conditions- Depth

Hydronia RiverFlo 2D SMS Model Output based on 100 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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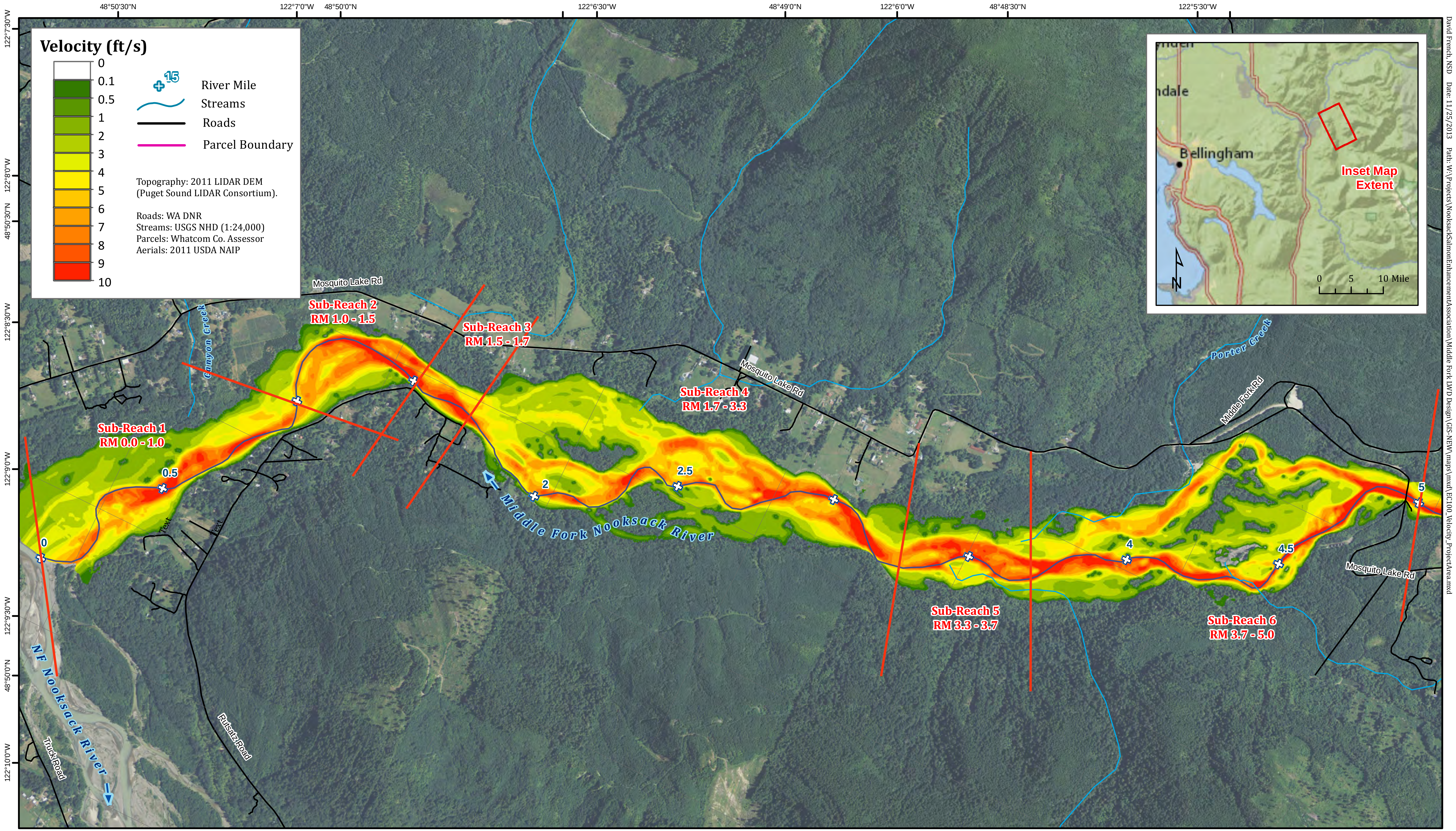

Middle Fork Nooksack River LWD Preliminary Design

100 Year Model Output - Project Area

Existing Conditions- Velocity

Hydronia RiverFlo 2D SMS Model Output based on 100 year flow event

0 1,000 2,000 3,000 4,000 Feet

Lambert conformal conic projection, NAD 1983
State Plane Coordinate System (WA North Zone)

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APPENDIX B

CONCEPTUAL DESIGN DRAWINGS

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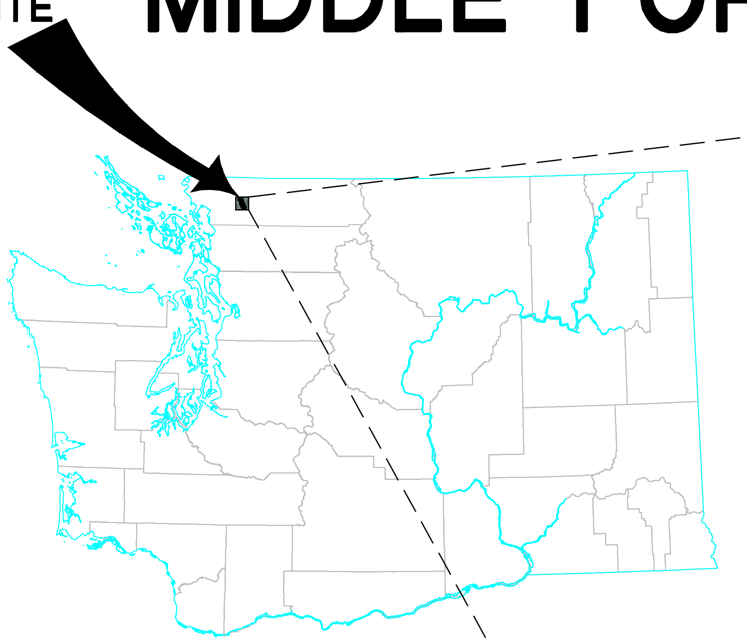
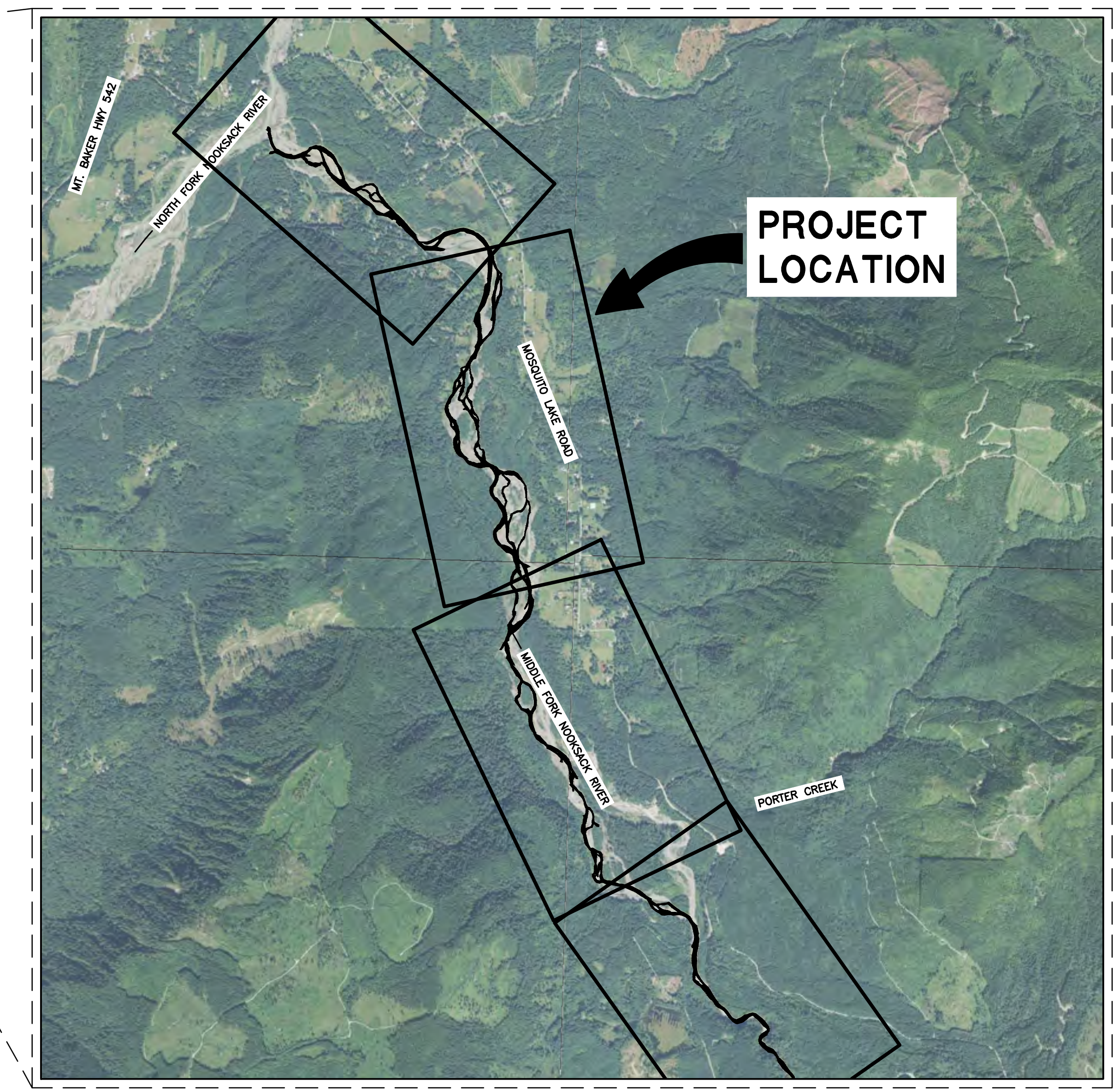
MIDDLE FORK NOOKSACK LWD DESIGN RMO. S.O.

SITE



WASHINGTON STATE
SCALE: 1"=50 MILES



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VICINITY MAP
SCALE:1" = 2000'

Sheet List Table	
Sheet Number	Sheet Title
1	COVER SHEET
2	GENERAL NOTES
3	LEGEND
4	SITE 1
5	SITE 2
6	SITE 3
7	SITE 4
8	TYPE 1 ELJ
9	TYPE 2 ELJ
10	TYPE 3 ELJ

CONTACT INFORMATION

NATURAL SYSTEMS DESIGN, INC
1900 N NORTHLAKE WAY, SUITE 211
SEATTLE, WA 98103
(206) 834-0175

NOOKSACK SALMON ENHANCEMENT ASSOCIATION
2445 E BAKERVIEW ROAD
BELLINGHAM, WA 98226
(360) 715-0283

Nov-08-2013 ---- CONCEPT DESIGN

0 Ø 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

NSEA
NOOKSACK SALMON ENHANCEMENT ASSOCIATION

Natural Systems Design

NAME OR INITIALS AND DATE		GEOGRAPHIC INFORMATION	
DESIGNED	--	LATITUDE	48°49'00"N
CHECKED	--	LONGITUDE	122°08'00"W
DRAWN	--	TN/SC/RG	T38N/S2/R5E
CHECKED	--	DATE	-

MIDDLE FORK NOOKSACK

COVER SHEET

1

SHEET 1 OF 11

N:\PROJECTS\NOOKSACKSALMONENHANCEMENTASSOCIATION\MIDDLE FORK LWD DESIGN\DESIGN\CAD DWGS-CURRENT\COVER SHEET.DWG Mackenzie 5/1/2013 9:26:19 AM

GENERAL NOTES

1. THESE PLANS HAVE BEEN PREPARED FOR THE EXCLUSIVE USE OF NOOKSACK SALMON ENHANCEMENT ASSOCIATION, HEREAFTER REFERRED TO AS "OWNER" AND "CONTRACTOR" AND THEIR AUTHORIZED AGENTS.
2. NATURAL SYSTEMS DESIGN HEREAFTER REFERRED TO AS "ENGINEER" IS RESPONSIBLE FOR THE PREPARATION OF THESE ORIGINAL PLANS AND ASSOCIATED SPECIFICATIONS AND WILL NOT BE RESPONSIBLE FOR, OR LIABLE FOR UNATHORIZED CHANGES TO OR USES OF THESE PLANS. ANY USE WHICH INCLUDES ALTERATION, DELETION, OR EDITING OF THIS DOCUMENT WITHOUT EXPLICIT WRITTEN PERMISSION FROM THE ENGINEER, IS STRICTLY PROHIBITED. ANY OTHER UNAUTHORIZED USE OF THIS DOCUMENT IS PROHIBITED.
3. MINOR MODIFICATIONS ARE EXPECTED TO SUIT JOB SITE DIMENSIONS OR CONDITIONS. SUCH MODIFICATIONS SHALL BE INCLUDED AS PART OF THE WORK. THE OWNER, ENGINEER AND APPROPRIATE REGULATORY AGENCIES WILL BE NOTIFIED OF ANY OWNER-AUTHORIZED CHANGE RESULTING IN MORE THAN A 10% DESIGN CHANGE OF PROPOSED FOOTPRINT OR SIGNIFICANTLY AFFECTING THE INTENDED BENEFIT OR FUNCTION OF A PROJECT ELEMENT.
4. THE LOCATION OF ALL FEATURES SHOWN IS APPROXIMATE.
5. THE CONTRACTOR AGREES TO ASSUME SOLE AND COMPLETE RESPONSIBILITY FOR JOB SITE CONDITIONS DURING THE COURSE OF CONSTRUCTION OF THIS PROJECT, INCLUDING SAFETY OF ALL PERSONS AND PROPERTY, AND FURTHER AGREES THAT THIS REQUIREMENT SHALL APPLY CONTINUOUSLY AND NOT BE LIMITED TO NORMAL WORKING HOURS IN ACCORDANCE WITH THE PROVISIONS OUTLINED BY THE PROJECT CONTRACT AND SPECIFICATIONS.
6. ALL IMPROVEMENTS SHALL BE ACCOMPLISHED UNDER THE APPROVAL, INSPECTION, AND TO THE SATISFACTION OF THE OWNER. IMPROVEMENT CONSTRUCTION SHALL COMPLY WITH THESE PLANS AND THE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION (WSDOT) STANDARD PLANS FOR CONSTRUCTION OF ROAD, BRIDGE, AND MUNICIPAL CONSTRUCTION, CURRENT EDITION UNLESS NOTED OTHERWISE. ALL REFERENCES TO THE "STANDARD SPECIFICATIONS" SHALL MEAN THE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION (WSDOT) STANDARD SPECIFICATIONS FOR CONSTRUCTION OF LOCAL STREETS AND ROADS, CURRENT EDITION. CONSTRUCTION NOT SPECIFIED ON THESE PLANS SHALL CONFORM TO THE REQUIREMENTS OF THE STANDARD SPECIFICATIONS. THE CONTRACTOR IS OBLIGATED TO BE FAMILIAR WITH APPLICABLE SECTIONS OF THE STANDARD SPECIFICATIONS NOT DISCUSSED IN THE GENERAL NOTES. THE CONTRACT SPECIAL PROVISIONS SHALL SUPERSEDE THOSE OF THE STANDARD SPECIFICATIONS WHERE DISCREPANCIES OCCUR.
7. IT IS THE RESPONSIBILITY OF THE CONTRACTOR AND HIS SUBCONTRACTOR(S) TO EXAMINE THE PROJECT SITE PRIOR TO THE OPENING OF BID PROPOSALS. THE CONTRACTOR SHALL BECOME FAMILIAR WITH THE CONDITIONS UNDER WHICH THE WORK IS TO BE PERFORMED, SUCH AS THE NATURE AND LOCATION OF THE WORK AND THE GENERAL AND LOCAL CONDITIONS, PARTICULARLY THOSE AFFECTING THE AVAILABILITY OF TRANSPORTATION, THE DISPOSAL, HANDLING, AND STORAGE OF MATERIALS, AVAILABILITY OF LABOR, WATER, ELECTRICITY, ROADS, THE UNCERTAINTIES OF WEATHER, THE CONDITIONS OF THE GROUND, SURFACE AND SUBSURFACE MATERIALS, GROUNDWATER, THE EQUIPMENT AND FACILITIES NEEDED FOR AND DURING THE PERFORMANCE OF THE WORK, AND THE COSTS THEREOF. ANY FAILURE BY THE CONTRACTOR AND SUBCONTRACTOR(S) TO ACQUAINT THEMSELVES WITH ALL THE AVAILABLE INFORMATION WILL NOT RELIEVE THE CONTRACTOR AND SUBCONTRACTOR(S) FROM RESPONSIBILITY FOR PROPERLY ESTIMATING THE DIFFICULTY AND COST OF SUCCESSFULLY PERFORMING THE WORK.
8. THE CONTRACTOR IS RESPONSIBLE FOR REVIEWING THE CONTRACT DOCUMENTS AND FOR ALL SUBMITTALS REQUIRED TO THE OWNER FOR REVIEW AND ACCEPTANCE.

PERMIT NOTES

1. EVERY REASONABLE EFFORT SHALL BE MADE TO CONDUCT THE ACTIVITIES SHOWN IN THESE PLANS, IN A MANNER THAT MINIMIZES THE ADVERSE IMPACT ON WATER QUALITY, FISH AND WILDLIFE, AND THE NATURAL ENVIRONMENT.
2. ALL WORK WILL BE IN COMPLIANCE WITH PERMIT CONDITIONS ISSUED BY VARIOUS REGULATORY AGENCIES. IT IS THE CONTRACTOR'S RESPONSIBILITY TO HAVE COPIES OF ALL PERMITS ON THE JOB SITE, UNDERSTAND AND COMPLY WITH ALL PERMIT CONDITIONS.
3. ALL WORK THAT DISTURBS THE SUBSTRATE, BANK, OR SHORE OF A WATERS OF THE STATE THAT CONTAINS FISH LIFE SHALL BE CONDUCTED ONLY DURING THE WORK PERIOD FOR THAT WATERBODY AS INDICATED IN THE MOST RECENT ALLOWABLE WORK PERIODS FOR HYDRAULIC PROJECTS IN FRESHWATER FOR THE PROJECT AREA. THOSE PORTIONS OF THE PROJECT WORK THAT OCCUR OUTSIDE OR ABOVE THE ORDINARY HIGH WATER MARK (ABOVE THE CORPS JURISDICTIONAL LINE) ARE NOT SUBJECT TO THE WORK PERIODS DESCRIBED ABOVE UNLESS SPECIFIED IN THE RELEVANT PERMITS.
4. ALL ACTIVITIES THAT INVOLVE WORK ADJACENT TO OR WITHIN THE WETTED CHANNEL SHALL, AT ALL TIMES, REMAIN CONSISTENT WITH ALL APPLICABLE WATER QUALITY STANDARDS, EFFLUENT LIMITATION AND STANDARDS OF PERFORMANCE, PROHIBITIONS, PRETREATMENT STANDARDS, AND MANAGEMENT PRACTICES ESTABLISHED PURSUANT TO THE CLEAN WATER ACT OR PURSUANT TO APPLICABLE STATE AND LOCAL LAW.
5. IF AT ANY TIME, AS A RESULT OF PROJECT ACTIVITIES, FISH ARE OBSERVED IN DISTRESS, A FISH KILL OCCURS, OR WATER QUALITY PROBLEMS DEVELOP (INCLUDING EQUIPMENT LEAKS OR SPILLS), OPERATIONS SHALL CEASE AND THE OWNER SHALL BE NOTIFIED IMMEDIATELY.
6. IF, DURING CONSTRUCTION, ARCHAEOLOGICAL REMAINS ARE ENCOUNTERED, CONSTRUCTION IN THE VICINITY SHALL BE HALTED, AND THE STATE OFFICE OF HISTORIC PRESERVATION AND THE OWNER SHALL BE NOTIFIED IMMEDIATELY.

SURVEY NOTES

1. UNLESS NOTED OTHERWISE ON THE PLANS, THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE PROTECTION OF ALL EXISTING SURVEY MONUMENTS AND OTHER SURVEY MARKERS DURING CONSTRUCTION.
2. THE CONTRACTOR SHALL MAINTAIN A SET OF PLANS ON THE JOB SHOWING "AS-CONSTRUCTED" CHANGES MADE TO DATE. UPON COMPLETION OF THE PROJECT, THE CONTRACTOR SHALL SUPPLY TO OWNER A SET OF PLANS, MARKED UP TO THE SATISFACTION OF THE OWNER, REFLECTING THE AS-CONSTRUCTED MODIFICATIONS.
3. ELEVATIONS SHOWN ON THE PLANS FOR PIPE INVERTS, TOPS OF BANKS, THALWEG, GRADE CONTROLS, ETC., ARE BASED UPON THE TOPOGRAPHIC INFORMATION SHOWN ON THE PLANS. THE CONTRACTOR SHALL VERIFY ALL NECESSARY SURFACE ELEVATIONS IN THE FIELD AND NOTIFY THE OWNER OF ANY DISCREPANCIES, WHICH MIGHT AFFECT PROPER OPERATION OF THE NEW FACILITIES BEFORE BREAKING GROUND AND PRIOR TO FACILITY INSTALLATION. THE OWNER SHALL BE CONTACTED IN THE EVENT ELEVATIONS ARE INCORRECT SO THAT THE PROPER ADJUSTMENTS CAN BE MADE BY ENGINEER PRIOR TO THE INSTALLATION OF THE FACILITIES, AS SET FORTH IN THE SPECIAL PROVISIONS.
4. LIDAR FOR THIS PROJECT WAS PROVIDED FOR PUGET SOUND LIDAR CONSORTIUM BY WATERSHED SCIENCES, INC. AND IS REPRESENTATIVE OF 2011 CONDITIONS. THE VERTICAL DATUM IS NAVD 88 (FT) GEOID03. THE HORIZONTAL DATUM IS NAD 83 WASHINGTON STATE PLANE FIPS 4601, US SURVEY FT.

EROSION, SEDIMENT CONTROL AND WATER MANAGEMENT NOTES

1. THE CONTRACTOR SHALL BE RESPONSIBLE FOR IMPLEMENTING ALL TEMPORARY EROSION CONTROL MEASURES. THE EROSION CONTROL MEASURES SHALL BE IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REQUIREMENTS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE MAINTENANCE AND PERFORMANCE OF THE TEMPORARY EROSION CONTROL MEASURES THROUGHOUT THE DURATION OF THE PROJECT.
2. A SEDIMENT AND EROSION CONTROL PLAN WILL BE DEVELOPED BY THE CONTRACTOR AND SUBMITTED FOR APPROVAL BY OWNER AND/OR THE ENGINEER BEFORE ANY CONSTRUCTION MAY BEGIN. THE SEDIMENT AND EROSION CONTROL PLAN WILL IDENTIFY BEST MANAGEMENT PRACTICES TO ENSURE THAT THE TRANSPORT OF SEDIMENT TO SURFACE WATERS, DRAINAGE SYSTEMS, AND ADJACENT PROPERTIES IS MINIMIZED.
3. ACTIVITIES SHALL BE DESIGNED AND CONSTRUCTED TO AVOID AND MINIMIZE ADVERSE IMPACTS TO WATERS OF THE UNITED STATES TO THE MAXIMUM EXTENT PRACTICAL THROUGH THE USE OF PRACTICAL ALTERNATIVES. ALTERNATIVES THAT SHALL BE CONSIDERED INCLUDE THOSE THAT MINIMIZE THE NUMBER AND EXTENT OF IN-WATER WORK AND EQUIPMENT CROSSINGS OF WETTED CHANNELS.
4. AT NO TIME SHALL SEDIMENT-LADEN WATER BE DISCHARGED OR PUMPED DIRECTLY INTO THE SUBJECT RIVER, STREAM, OR WETLAND. WATER SHALL BE DISCHARGED IN ACCORDANCE WITH REQUIREMENTS SET FORTH IN THE PROJECT PERMITS AND / OR SPECIFICATIONS.
5. IF HIGH WATER LEVEL CONDITIONS THAT CAUSE SILTATION OR EROSION ARE ENCOUNTERED DURING CONSTRUCTION, WORK SHALL STOP UNTIL THE WATER LEVEL SUBSIDES.
6. PERMIT CONDITIONS CONTAIN SPECIFIC REQUIREMENTS FOR THE CONTROL OF EROSION AND TURBIDITY FROM PROJECT OPERATIONS. TURBIDITY WILL BE MONITORED ON A FREQUENT BASIS BY THE PROJECT MANAGEMENT AND INSPECTION STAFF ON-SITE. TURBIDITY AMOUNTS IN EXCESS OF THE PERMITTED CONCENTRATIONS AND/OR DURATIONS WILL CAUSE WORK TO BE STOPPED UNTIL IMPROVED PRACTICES ARE IN EFFECT AND THE PROBLEMS CONTROLLED. THE CONTRACTOR IS COMPLETELY RESPONSIBLE FOR ANY PROJECT DELAYS THAT OCCUR BY NATURE OF THIS FAILURE TO ADEQUATELY CONTAIN SEDIMENT ON-SITE.
7. CONTRACTOR SHALL LIMIT MACHINERY MOVEMENT TO CONSTRUCTION AREAS DEFINED ON SITE PLAN OR IDENTIFIED AS ACCEPTABLE BY THE ENGINEER OR OWNER.
8. ALL EXTERNAL GREASE AND OIL SHALL BE PRESSURE-WASHED OFF THE EQUIPMENT PRIOR TO TRANSPORT TO THE SITE.
9. THE CONTRACTOR IS RESPONSIBLE TO ENSURE THAT NO PETROLEUM PRODUCTS, HYDRAULIC FLUID, SEDIMENTS, SEDIMENT-LADEN WATER, CHEMICALS, OR ANY OTHER TOXIC OR DELETERIOUS MATERIALS ARE ALLOWED TO ENTER OR LEACH INTO THE SUBJECT RIVER, STREAM, OR WETLAND.
10. THE CONTRACTOR SHALL HAVE AN EMERGENCY SPILL KIT ONSITE AT ALL TIMES.
11. NO TREES OR WETLAND VEGETATION SHALL BE REMOVED UNLESS THEY ARE SHOWN AND NOTED TO BE REMOVED ON THE PLANS OR AS DIRECTLY SPECIFIED ON-SITE BY THE PROJECT MANAGEMENT STAFF. ALL TREES CONFLICTING WITH GRADING SHALL BE REMOVED. NO GRADING SHALL TAKE PLACE WITHIN THE DRIP LINE OF TREES NOT TO BE REMOVED UNLESS OTHERWISE APPROVED.
12. FOLLOWING CONSTRUCTION, SITE RESTORATION WILL INCLUDE ESTABLISHING LONG-TERM EROSION PROTECTION MEASURES. THESE MEASURES WILL INCLUDE PLANTINGS, EROSION CONTROL FABRIC, SEED, AND MULCH. EQUIPMENT AND EXCESS SUPPLIES WILL BE REMOVED AND THE WORK AREA WILL BE CLEANED. MAINTENANCE ACTIVITIES FOR THE NEWLY CONSTRUCTED RESTORATION PROJECTS ARE ANTICIPATED TO OCCUR PERIODICALLY.

CONSTRUCTION NOTES

1. CONTRACT DOCUMENTS REFER TO THESE PLANS.
2. CONTRACTOR SHALL FURNISH ALL MATERIALS, EQUIPMENT, AND LABOR NECESSARY TO COMPLETE ALL WORK AS INDICATED IN THE CONTRACT DOCUMENTS.
3. CONSTRUCTION HOURS SHALL BE WEEKDAYS BETWEEN <u>7:00 A.M. AND 6:30 P.M</u>. UNLESS PRIOR APPROVAL IS RECEIVED FROM THE OWNER.
4. ANY DISCREPANCIES ARE TO BE BROUGHT TO THE ATTENTION OF THE OWNER PRIOR TO PROCEEDING WITH THE WORK.
5. THE CONTRACTOR SHALL INSTALL ALL EQUIPMENT AND MATERIALS IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS UNLESS SPECIFICALLY INDICATED OTHERWISE BY THE OWNER OR WHERE LOCAL CODES OR REGULATIONS TAKE PRECEDENCE.
6. ALL WORK PERFORMED AND MATERIALS INSTALLED SHALL BE IN STRICT ACCORDANCE WITH ALL APPLICABLE CODES, REGULATIONS, AND ORDINANCES.
7. THE CONTRACTOR SHALL SUPERVISE AND DIRECT THE WORK USING THE BEST SKILLS AND ATTENTION. THE CONTRACTOR SHALL BE SOLELY RESPONSIBLE FOR ALL CONSTRUCTION MEANS, METHODS, TECHNIQUES, SEQUENCES, AND PROCEDURES AND FOR COORDINATING ALL PORTIONS OF THE WORK UNDER THIS CONTRACT.
8. THE CONTRACTOR SHALL MAKE ALL NECESSARY PROVISIONS TO PROTECT EXISTING IMPROVEMENTS, ROADWAY, DRAINAGE WAYS, PRIVATE BRIDGE, CULVERTS, AND VEGETATION UNTIL SUCH ITEMS ARE TO BE DISTURBED OR REMOVED AS INDICATED ON THE CONTRACT DOCUMENTS.
9. THE CONTRACTOR SHALL KEEP THE JOB SITE CLEAN AND HAZARD FREE. CONTRACTOR SHALL DISPOSE OF ALL DIRT, DEBRIS, AND RUBBISH FOR THE DURATION OF THE WORK. UPON COMPLETION OF WORK, CONTRACTOR SHALL REMOVE ALL MATERIAL AND EQUIPMENT NOT SPECIFIED AS REMAINING ON THE PROPERTY.
10. NOTES AND DETAILS ON THE PLANS SHALL TAKE PRECEDENCE OVER GENERAL NOTES HEREIN.
11. DIMENSIONS CALLOUTS SHALL TAKE PRECEDENCE OVER SCALES SHOWN ON THE PLANS.
12. THE PLANS REPRESENT THE FINISHED STRUCTURE. THEY DO NOT INDICATE THE METHOD OF ALL CONSTRUCTION. THE CONTRACTOR SHALL PROVIDE ALL MEASURES NECESSARY TO PROTECT THE STRUCTURES, WORKS, AND THE PUBLIC DURING CONSTRUCTION.
13. MATERIAL SHALL NOT BE STORED OUTSIDE OF IDENTIFIED STAGING AREAS. THE CONTRACTOR SHALL USE ONLY DESIGNATED SPECIFIC SITES FOR STORAGE OF EQUIPMENT AND MATERIALS AS SHOWN ON THESE PLANS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE SECURITY OF ALL EQUIPMENT AND MATERIALS.

Nov-08-2013 ---- CONCEPT DESIGN

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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

NSEA
NOOKSACK SALMON ENHANCEMENT ASSOCIATION

Natural Systems Design

NAME OR INITIALS AND DATE		GEOGRAPHIC INFORMATION	
DESIGNED	--	LATITUDE	48°49'00"N
CHECKED	--	LONGITUDE	122°08'00"W
DRAWN	--	TN/SC/RG	T38N/S2/R5E
CHECKED	--	DATE	-

MIDDLE FORK NOOKSACK

GENERAL NOTES

2

SHEET 2 OF 11

GENERAL LEGEND

- PROPERTY LINE
- PHASE LINE
- RIGHT OF WAY LINE (ROW)
- EXISTING ROAD
- ACCESS ROAD
- CLEARING LIMIT (CL)
- GRADING LIMIT (GL)
- EXISTING MAJOR CONTOUR (5)
- EXISTING MINOR CONTOUR (1)
- PROPOSED MAJOR CONTOUR (5)
- PROPOSED MINOR CONTOUR (1)
- LOW FLOW CHANNEL
- EXISTING FLOW
- EXISTING OHWM (OHWM)
- PROPOSED OHWM (OHWM)
- MEAN HIGHER HIGH WATER (MHHW)
- MEAN HIGH WATER (MHW)
- MEAN LOWER LOW WATER (MLLW)
- 2-YEAR FLOOD BOUNDARY (2-YR)
- 100-YEAR FLOOD BOUNDARY (100-YR)
- EXISTING STORM SEWER (SD)
- EXISTING SANITARY SEWER (SS)
- EXISTING WETLAND (WL)
- PROPOSED WETLAND (WL)
- EXISTING WATER (W)
- PROPOSED WATER (W)
- DEMOLITION/REMOVAL AREA
- EXISTING FENCE
- EXISTING CONIFEROUS TREE
- EXISTING DECIDUOUS TREE
- CONTROL POINT LOCATION
- PHOTO POINT LOCATION
- RACKING AND SLASH MATERIAL
- LARGE WOOD PIECE
- ENGINEERED LOGJAM TYPE 1, SEE SHEET 8 – TYPE 1 ELJ
- ENGINEERED LOGJAM TYPE 2, SEE SHEET 9 – TYPE 2 ELJ
- ENGINEERED LOGJAM TYPE 3, SEE SHEET 10 – TYPE 3 ELJ
- NATIVE ALLUVIUM
- STREAMBED GRAVEL
- RIPRAP
- BOULDER CLUSTER
- STEEL CABLE

RESTORATION LEGEND

- FILL SLOPE LINE
- EXCAVATION SLOPE LINE
- SWALE
- FLOODPLAIN MOUNDS
- FLOODPLAIN DEPRESSIONS
- TRAIL EDGE
- RIPARIAN
- FLOODPLAIN
- UPLAND UNDERPLANTING
- WETLAND UNDERPLANTING

TEMPORARY EROSION CONTROL LEGEND

- SILT BOOM (SB)
- BLOCK NETS (BN)
- SILT FENCE (SF)
- STRAW WATTLE (SW)
- PROPOSED STREAM BYPASS
- PROPOSED STAGING AREA
- BULK BAG COFFERDAM
- TEMPORARY ACCESS ROAD
- PUMP OUTLET LOCATION

DETAIL AND SECTION REFERENCING

1	NOTE REFERENCING NUMBER
4 / 6	DETAIL REFERENCE NUMBER SHEET ON WHICH DETAIL APPEARS
4 / 2	DETAIL REFERENCE NUMBER SHEET ON WHICH DETAIL APPEARS
(TYP)	SPECIFIES THAT DETAIL IS UNIFORMLY TYPICAL THROUGHOUT PROJECT EXCEPT WHERE OTHERWISE NOTED
(VAR)	SPECIFIES THAT DETAIL WAS TAKEN FROM SEVERAL SHEETS
A A32	SECTION A–A IS SHOWN ON SHEET 32
SECTION A–A 32 SCALE: NTS	SECTION A–A IS SHOWN ON SHEET 32

0 Ø 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

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NOOKSACK SALMON ENHANCEMENT ASSOCIATION

Natural Systems Design

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DESIGNED	--
CHECKED	--
DRAWN	--
CHECKED	--

GEOGRAPHIC INFORMATION	
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LONGITUDE	122°08'00"W
TN/SC/RG	T38N/S2/R5E
DATE	–

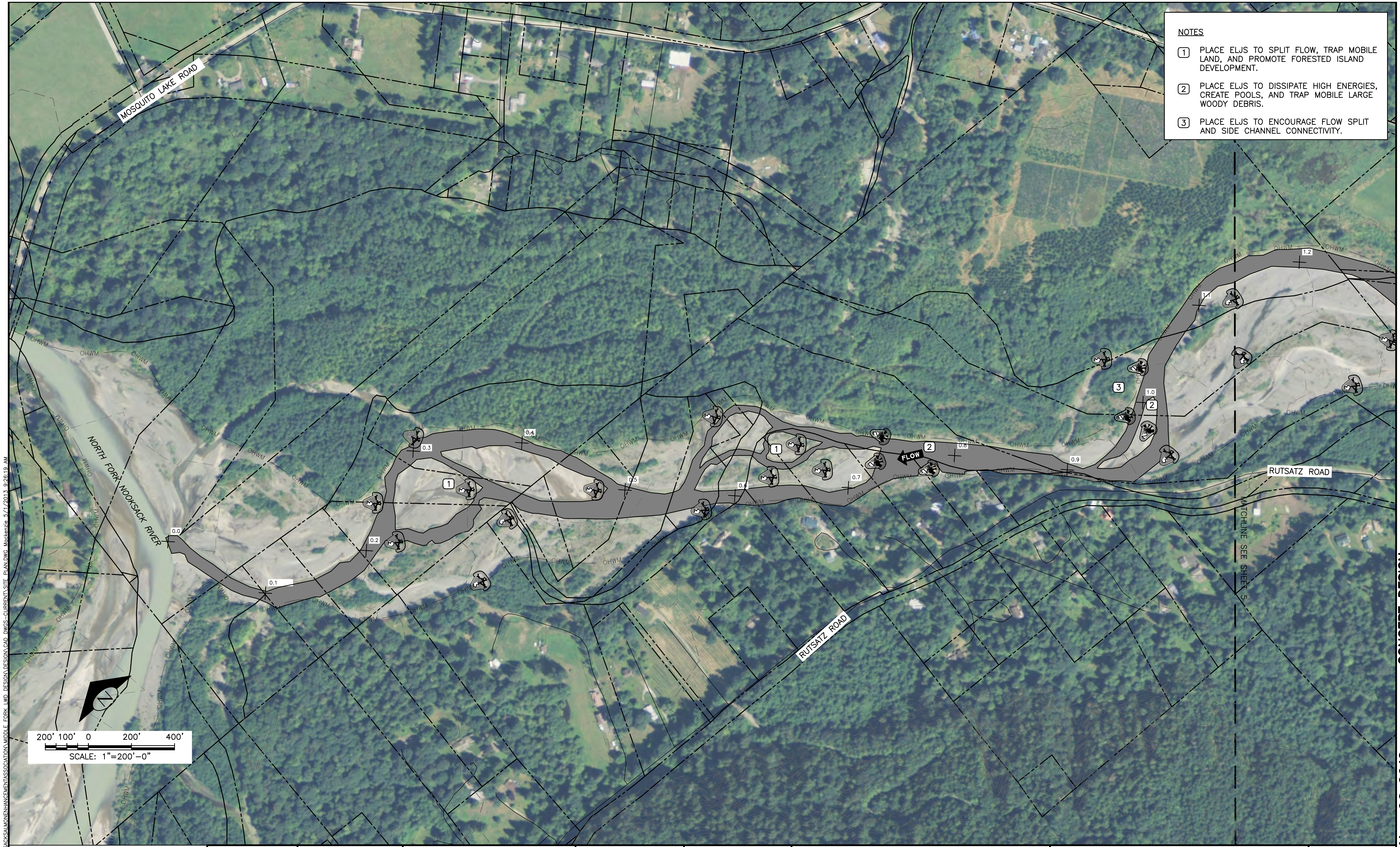
MIDDLE FORK NOOKSACK

LEGEND

3

SHEET 3 OF 11

Nov-08-2013 ---- CONCEPT DESIGN



NOTES

1. PLACE ELJS TO SPLIT FLOW, TRAP MOBILE LAND, AND PROMOTE FORESTED ISLAND DEVELOPMENT.
2. PLACE ELJS TO DISSIPATE HIGH ENERGIES, CREATE POOLS, AND TRAP MOBILE LARGE WOODY DEBRIS.
3. PLACE ELJS TO ENCOURAGE FLOW SPLIT AND SIDE CHANNEL CONNECTIVITY.

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Nov-08-2013 ---- CONCEPT DESIGN

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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

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NOOKSACK SALMON ENHANCEMENT ASSOCIATION

Natural Systems Design

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DESIGNED	--
CHECKED	--
DRAWN	--
CHECKED	--

GEOGRAPHIC INFORMATION	
LATITUDE	48°49'00"N
LONGITUDE	122°08'00"W
TN/SC/RG	T38N/S2/R5E
DATE	-

MIDDLE FORK NOOKSACK

SITE 1

4

SHEET 4 OF 11

CONCEPT DESIGN

Nov-08-2013

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MIDDLE FORK NOOKSACK	SITE 2	5 SHEET 5 OF 11

N:\PROJECTS\NOOKSACKSALMONENHANCEMENTASSOCIATION\MIDDLE FORK LWD DESIGN\DESIGN\CAD DWGS-CURRENT\SITE PLAN.DWG Mackenzie 5/1/2013 9:26:19 AM

Nov-08-2013 ---- CONCEPT DESIGN

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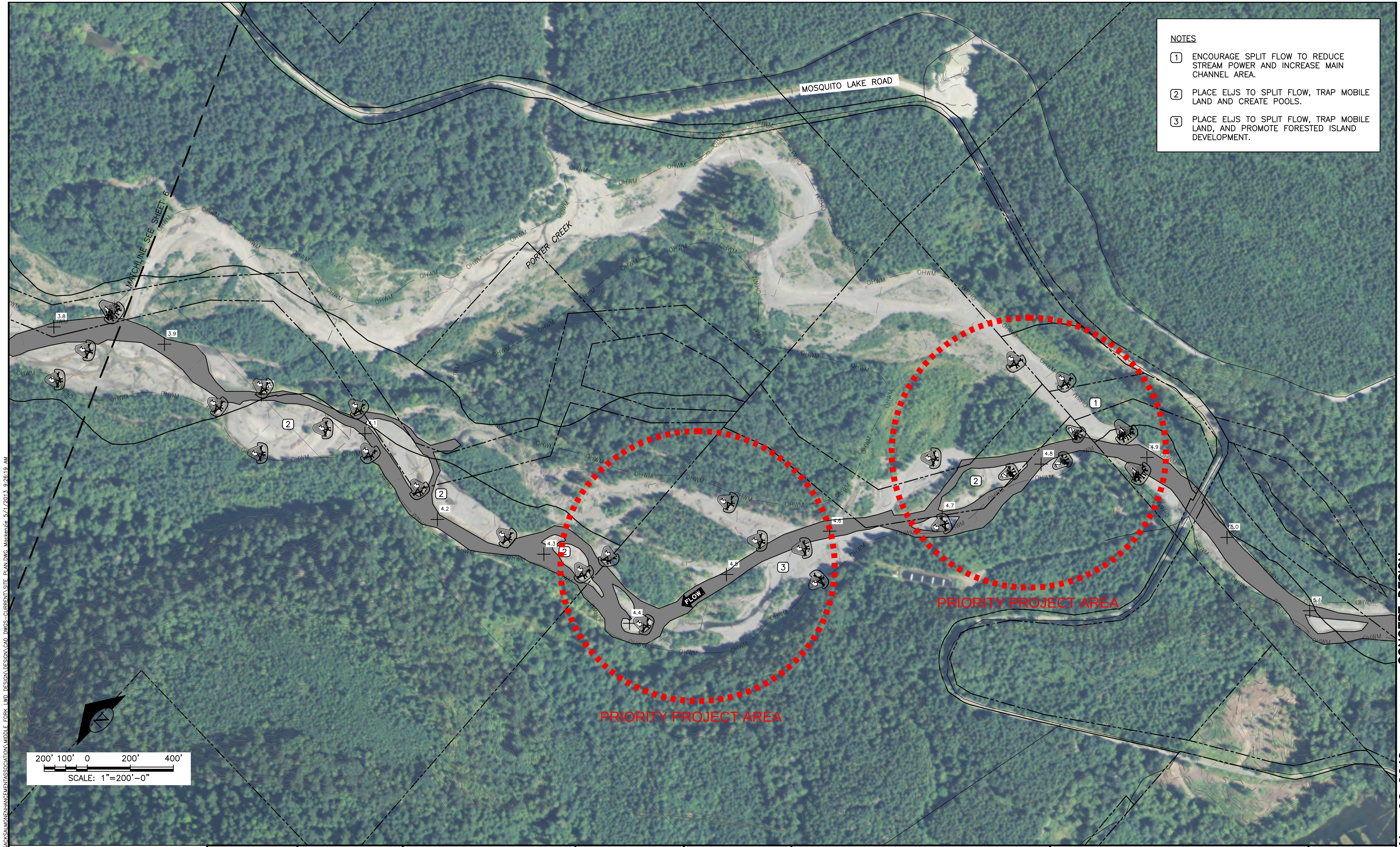

NOTES

1. ENCOURAGE SPLIT FLOW TO REDUCE STREAM POWER AND INCREASE MAIN CHANNEL AREA.
2. PLACE ELJS TO SPLIT FLOW, TRAP MOBILE LAND AND CREATE POOLS.
3. PLACE ELJS TO SPLIT FLOW, TRAP MOBILE LAND, AND PROMOTE FORESTED ISLAND DEVELOPMENT.

CONCEPT DESIGN
Nov-08-2013

IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

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Natural Systems Design

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CHECKED	--
DRAWN	--
CHECKED	--

GEOGRAPHIC INFORMATION	
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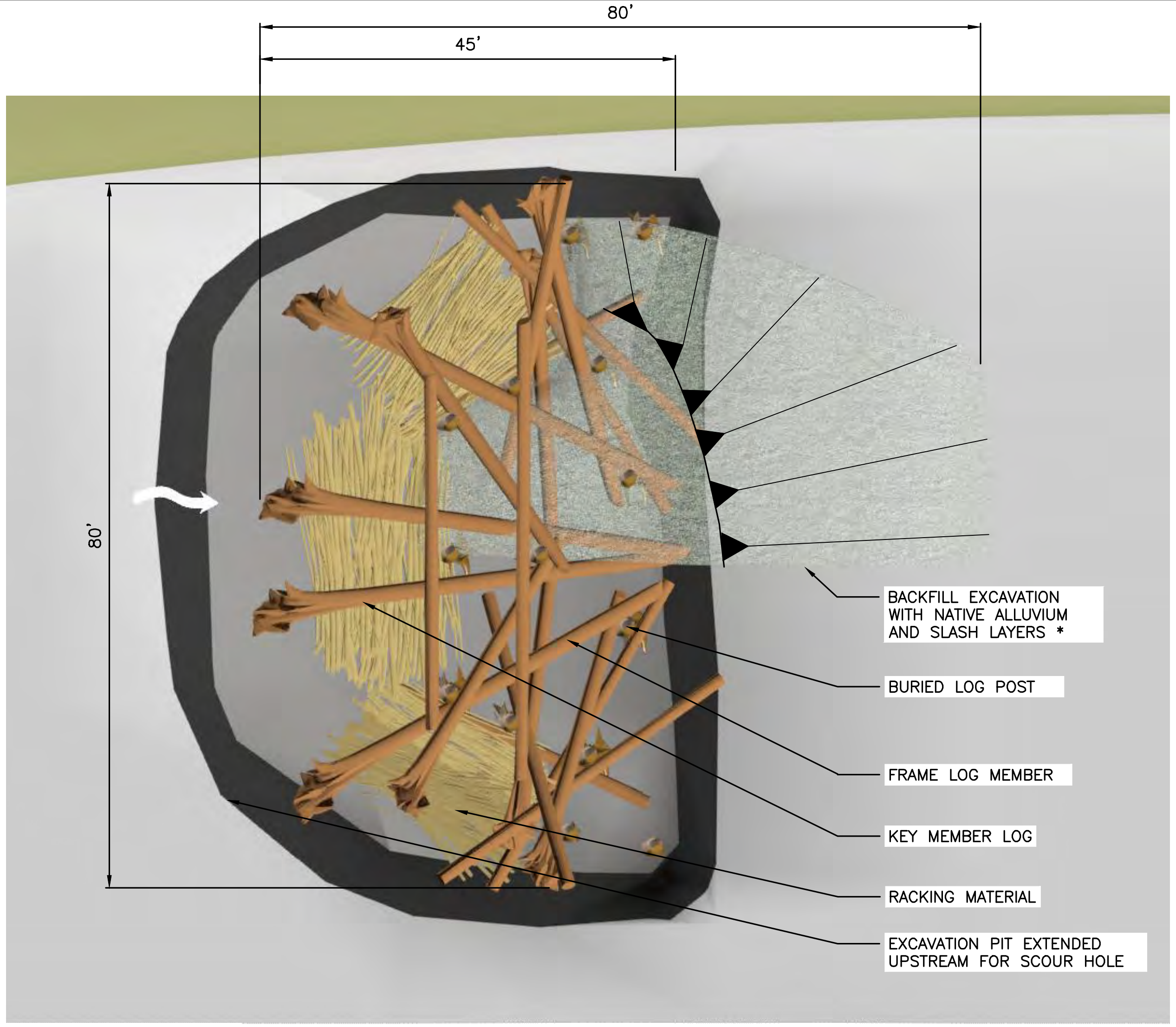
TN/SC/RG	T38N/S2/R5E
DATE	-

MIDDLE FORK NOOKSACK

SITE 4

7

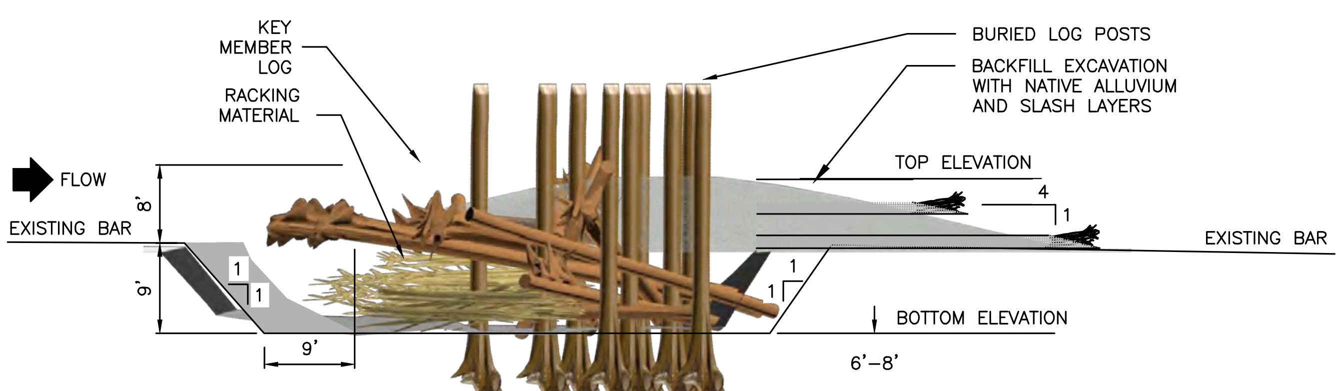
SHEET 7 OF 11



* ONLY HALF OF BACKFILL
SHOWN FOR CLARITY

TYPE 1 ELJ PLAN

SCALE: 1"=10'



TYPE 1 ELJ PROFILE

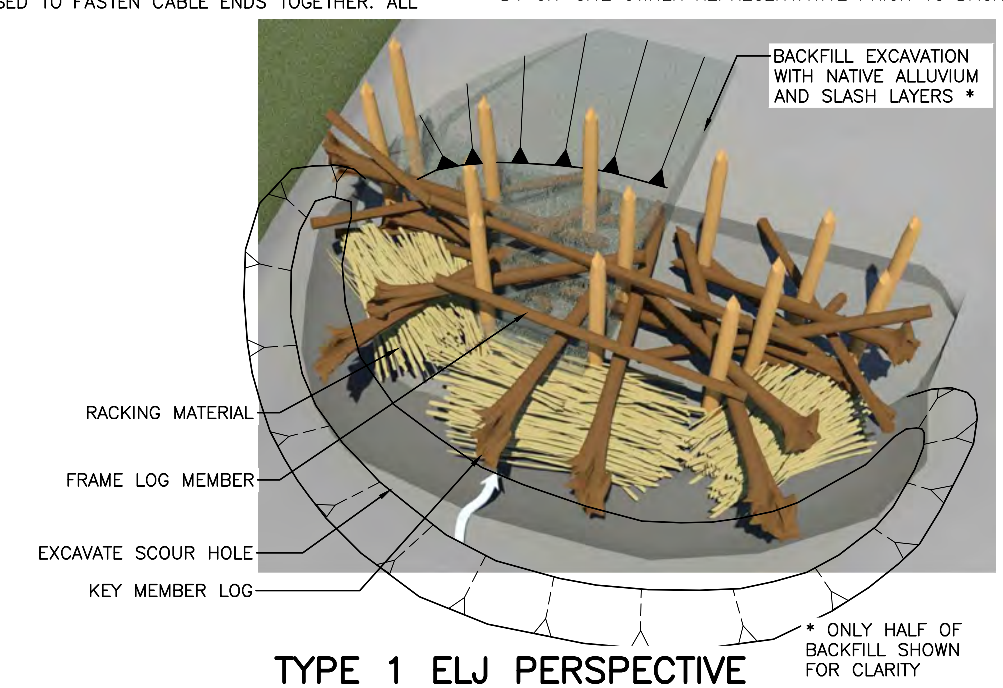
SCALE: 1"=10'

TYPE 1 STRUCTURE SCHEDULE

STRUCTURE LABEL*	**	**	**
STRUCTURE WIDTH, (FT)	**	**	**
STRUCTURE LENGTH, (FT)	**	**	**
SCOUR DEPTH, (FT)	**	**	**
MINIMUM FRAME LOG DIAMETER, (IN)	**	**	**
MINIMUM KEY LOG DIAMETER, (IN)	**	**	**
TIMBER POST DIAMETER, (IN)	**	**	**
GROUND ELEVATION AT STRUCTURE, (FT–NAVD88)	**	**	**
STRUCTURE BOTTOM ELEVATION, (FT–NAVD88)	**	**	**
TOP LOG ELEVATION, (FT–NAVD88)	**	**	**
STRUCTURE TOP ELEVATION, (FT–NAVD88)	**	**	**
MINIMUM PILE TIP ELEVATIONS, (FT–NAVD88)	**	**	**
AVERAGE SEPTEMBER WATER SURFACE ELEVATION (FT–NAVD 88)	**	**	**
* LABEL FORMAT, PHASE–ELJ TYPE–ELJ NUMBER			
**TBD – TO BE DETERMINED AND VERIFIED AT FINAL DESIGN PHASE			

TYPE 1 STRUCTURE NOTES:

1. EXCAVATE IN FRONT OF LOGJAM FOR PLACEMENT OF RACKING MATERIAL. EXCAVATION AREA SHALL NOT BE BACKFILLED WITH ALLUVIUM, BUT LEFT AS A SCOUR HOLE.
2. EXCAVATION SPOILS SHALL BE STAGED ACCORDING TO THE SWPPP. SPOILS SHALL ALSO BE STOCKPILED TO ALLOW LOG LAYER PLACEMENT AND CONSTRUCTION ACCESS.
3. BACKFILL EXTENTS MAY VARY AND TO BE CONSTRUCTED WITH NATIVE ALLUVIUM FROM EXCAVATION SPOILS.
4. BACKFILL EACH STRUCTURE LAYER WITH NATIVE ALLUVIUM FLUSH WITH THE CURRENT LAYER PRIOR TO PLACEMENT OF THE SUBSEQUENT LAYER.
5. FINAL ELJ HEIGHT TO BE ACHIEVED AS SPECIFIED REGARDLESS OF ACTUAL LOG DIAMETERS USED OR STACKING ARRANGEMENT.
6. ALL LARGE WOOD DIMENSIONS DO NOT INCLUDE BARK THICKNESS.
7. COVER TOP OF BACKFILL AREA AND BASE OF STRUCTURES 6–12 INCHES WITH LOOSE WOOD DEBRIS AND CHIPS.
8. CABLE FRAME LOG MEMBERS PER INSTRUCTIONS ON LAYERING PLAN TO VERTICAL POSTS WITH 1/2 INCH GALVANIZED STEEL CABLE AND 4 CABLE CLAMPS PER LASHING. STAPLES WILL NOT BE USED TO FASTEN CABLE ENDS TOGETHER. ALL CLAMPS AND HAND SPLICING SHALL BE PER THE MANUFACTURER SPECIFICATIONS TIGHTEN CABLE TO APPROXIMATELY 500–POUNDS TENSION.
9. RACKING MATERIAL SHALL CONSIST OF APPROXIMATELY 500 INDIVIDUAL LOGS PER STRUCTURE WITH 6" – 12" DIA DBH AND A MINIMUM OF 5–FEET LENGTH. RACKING PLACEMENT SHALL OCCUR WITH EACH LAYER PLACEMENT TO ENSURE RACKING MATERIAL EXTENDS THROUGH STRUCTURE AND PINNED IN PLACE BY SUBSEQUENT LAYERS.
10. THE CONTRACTOR SHALL FIELD VERIFY WITH THE OWNER REPRESENTATIVE OR ENGINEER ALL STRUCTURE LOCATIONS, PILE LOCATIONS, LENGTHS, WIDTHS AND ELEVATIONS PRIOR TO EXCAVATION, ASSEMBLY AND INSTALLATION OF EACH STRUCTURE.
11. LOCATIONS FOR ALL STRUCTURE PLACEMENTS WILL BE STAKED IN FIELD BY THE ENGINEER OR OWNER REPRESENTATIVE PRIOR TO START OF CONSTRUCTION.
12. EXCAVATION LIMITS SHALL BE FIELD VERIFIED BY THE OWNER REPRESENTATIVE OR ENGINEER PRIOR TO EXCAVATION COMMENCING AND PLACEMENT OF ANY LARGE WOOD.
13. LOG TYPE IDENTIFICATION SHALL BE PAINTED ON ALL LOGS BY THE CONTRACTOR IN A PLACE VISIBLE FOR FIELD VERIFICATION PRIOR TO PLACEMENT WITH LEAD–FREE, BLAZE–ORANGE SURVEY MARKING PAINT.
14. THE WOOD LAYER PLACEMENT IN EACH LOGJAM LAYER SHALL BE FIELD VERIFIED BY ON–SITE OWNER REPRESENTATIVE PRIOR TO BACKFILLING.



* ONLY HALF OF
BACKFILL SHOWN
FOR CLARITY

TYPE 1 ELJ PERSPECTIVE

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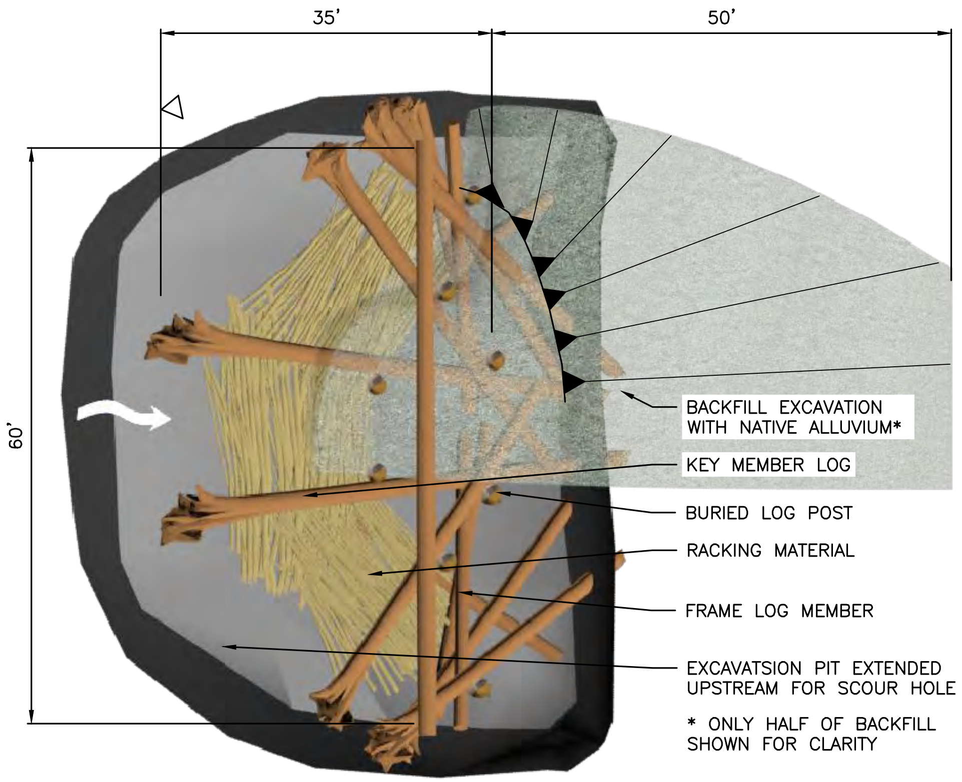
8

SHEET 8 OF 11



TYPE 2 ELJ PLAN

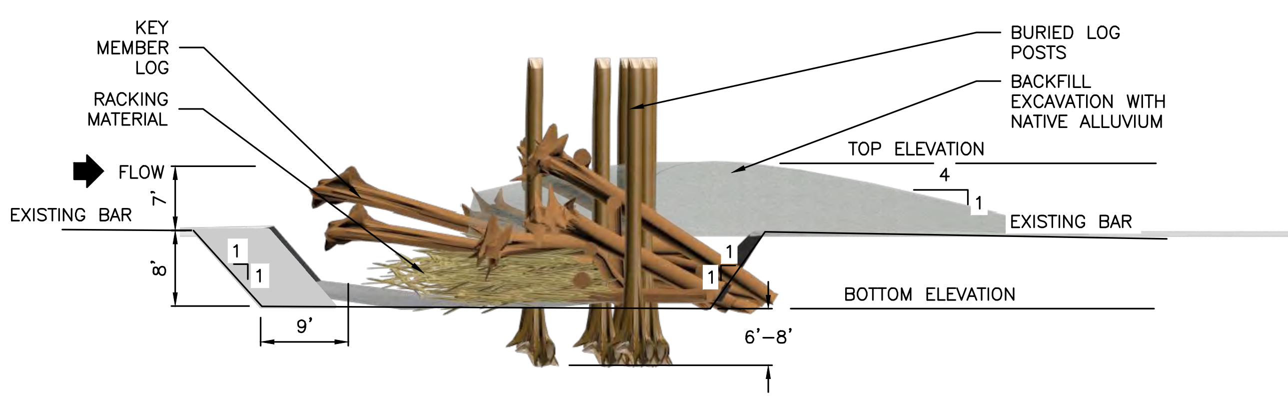
SCALE: 1" = 10'

TYPE 2 STRUCTURE SCHEDULE

STRUCTURE LABEL*	**	**	**
STRUCTURE WIDTH, (FT)	**	**	**
STRUCTURE LENGTH, (FT)	**	**	**
SCOUR DEPTH, (FT)	**	**	**
MINIMUM FRAME LOG DIAMETER, (IN)	**	**	**
MINIMUM KEY LOG DIAMETER, (IN)	**	**	**
TIMBER POST DIAMETER, (IN)	**	**	**
GROUND ELEVATION AT STRUCTURE, (FT–NAVD88)	**	**	**
STRUCTURE BOTTOM ELEVATION, (FT–NAVD88)	**	**	**
TOP LOG ELEVATION, (FT–NAVD88)	**	**	**
STRUCTURE TOP ELEVATION, (FT–NAVD88)	**	**	**
MINIMUM PILE TIP ELEVATIONS, (FT–NAVD88)	**	**	**
AVERAGE SEPTEMBER WATER SURFACE ELEVATION (FT–NAVD 88)	**	**	**
* LABEL FORMAT, PHASE–ELJ TYPE–ELJ NUMBER			
**TBD – TO BE DETERMINED AND VERIFIED AT FINAL DESIGN PHASE			

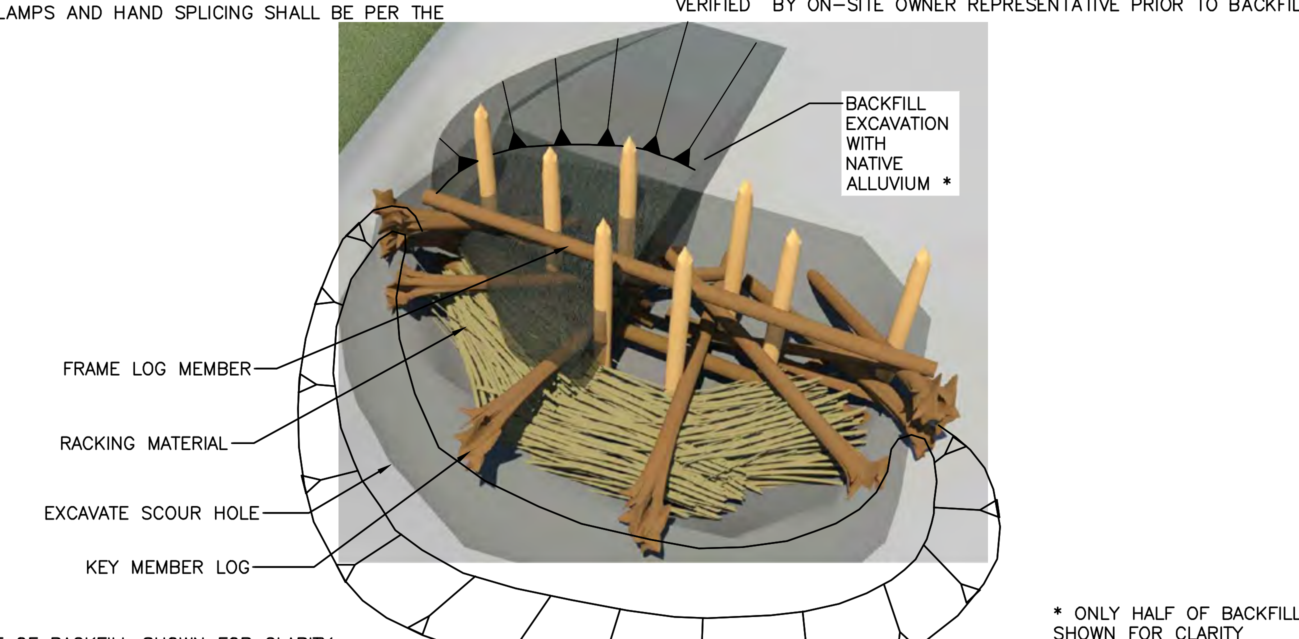
TYPE 2 STRUCTURE NOTES:

1. EXCAVATE IN FRONT OF LOGJAM FOR PLACEMENT OF RACKING MATERIAL. EXCAVATION AREA SHALL NOT BE BACKFILLED WITH ALLUVIUM, BUT LEFT AS A SCOUR HOLE.
2. EXCAVATION SPOILS SHALL BE STAGED ACCORDING TO THE SWPPP. SPOILS SHALL ALSO BE STOCKPILED TO ALLOW LOG LAYER PLACEMENT AND CONSTRUCTION ACCESS.
3. BACKFILL EXTENTS MAY VARY AND TO BE CONSTRUCTED WITH NATIVE ALLUVIUM FROM EXCAVATION SPOILS.
4. BACKFILL EACH STRUCTURE LAYER WITH NATIVE ALLUVIUM FLUSH WITH THE CURRENT LAYER PRIOR TO PLACEMENT OF THE SUBSEQUENT LAYER.
5. FINAL ELJ HEIGHT TO BE ACHIEVED AS SPECIFIED REGARDLESS OF ACTUAL LOG DIAMETERS USED OR STACKING ARRANGEMENT.
6. ALL LARGE WOOD DIMENSIONS DO NOT INCLUDE BARK THICKNESS.
7. COVER TOP OF BACKFILL AREA AND BASE OF STRUCTURES 6–12 INCHES WITH LOOSE WOOD DEBRIS AND CHIPS.
8. CABLE FRAME LOG MEMBERS PER INSTRUCTIONS ON LAYERING PLAN TO VERTICAL POSTS WITH 1/2 INCH GALVANIZED STEEL CABLE AND 4 CABLE CLAMPS PER LASHING. STAPLES WILL NOT BE USED TO FASTEN CABLE ENDS TOGETHER. ALL CLAMPS AND HAND SPLICING SHALL BE PER THE MANUFACTURER SPECIFICATIONS TIGHTEN CABLE TO APPROXIMATELY 500–POUNDS TENSION.
9. RACKING MATERIAL SHALL CONSIST OF APPROXIMATELY 500 INDIVIDUAL LOGS PER STRUCTURE WITH 6" – 12" DIA DBH AND A MINIMUM OF 5–FEET LENGTH. RACKING PLACEMENT SHALL OCCUR WITH EACH LAYER PLACEMENT TO ENSURE RACKING MATERIAL EXTENDS THROUGH STRUCTURE AND PINNED IN PLACE BY SUBSEQUENT LAYERS.
10. THE CONTRACTOR SHALL FIELD VERIFY WITH THE OWNER REPRESENTATIVE OR ENGINEER ALL STRUCTURE LOCATIONS, PILE LOCATIONS, LENGTHS, WIDTHS AND ELEVATIONS PRIOR TO EXCAVATION, ASSEMBLY AND INSTALLATION OF EACH STRUCTURE.
11. LOCATIONS FOR ALL STRUCTURE PLACEMENTS WILL BE STAKED IN FIELD BY THE ENGINEER OR OWNER REPRESENTATIVE PRIOR TO START OF CONSTRUCTION.
12. EXCAVATION LIMITS SHALL BE FIELD VERIFIED BY THE OWNER REPRESENTATIVE OR ENGINEER PRIOR TO EXCAVATION COMMENCING AND PLACEMENT OF ANY LARGE WOOD.
13. LOG TYPE IDENTIFICATION SHALL BE PAINTED ON ALL LOGS BY THE CONTRACTOR IN A PLACE VISIBLE FOR FIELD VERIFICATION PRIOR TO PLACEMENT WITH LEAD–FREE, BLAZE–ORANGE SURVEY MARKING PAINT.
14. THE WOOD LAYER PLACEMENT IN EACH LOGJAM LAYER SHALL BE FIELD VERIFIED BY ON–SITE OWNER REPRESENTATIVE PRIOR TO BACKFILLING.



TYPE 2 ELJ PROFILE

SCALE: 1" = 10'



* ONLY HALF OF BACKFILL SHOWN FOR CLARITY

TYPE 2 ELJ PERSPECTIVE

* ONLY HALF OF BACKFILL SHOWN FOR CLARITY

Nov-08-2013 ---- CONCEPT DESIGN

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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

NSEA NOOKSACK SALMON ENHANCEMENT ASSOCIATION

Natural Systems Design

NAME OR INITIALS AND DATE	
DESIGNED	RLE
CHECKED	--
DRAWN	--
CHECKED	--

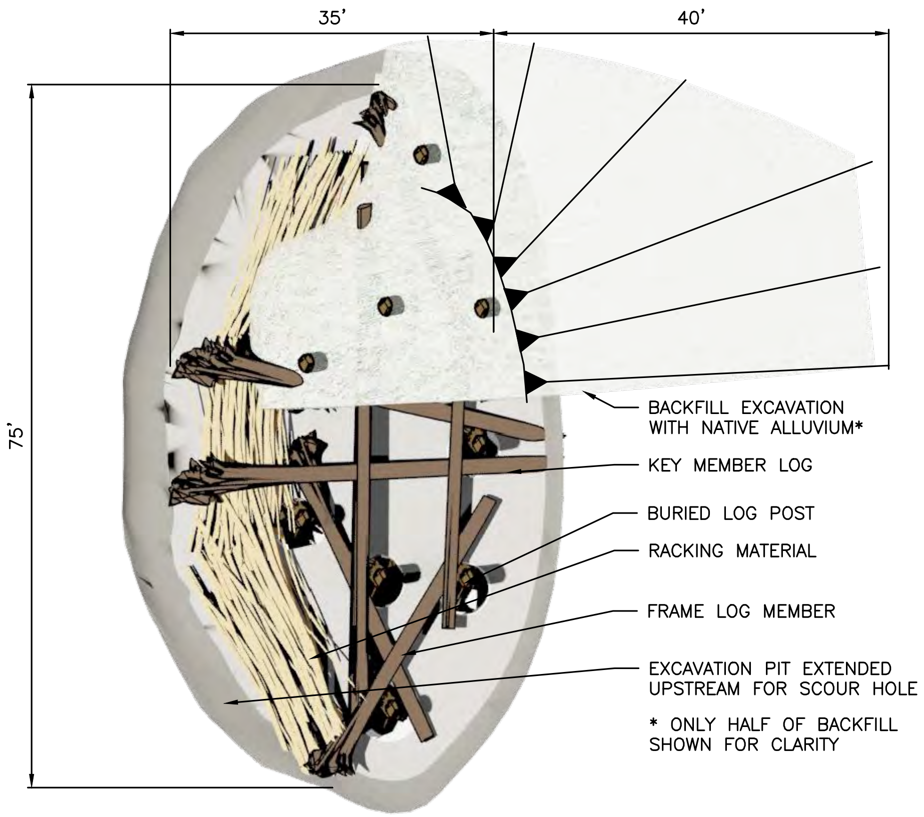
GEOGRAPHIC INFORMATION	
LATITUDE	48°49'00"N
LONGITUDE	122°08'00"W
TN/SC/RG	T38N/S2/R5E
DATE	–

MIDDLE FORK NOOKSACK

TYPE 2 ELJ

9

SHEET 9 OF 11



TYPE 3 ELJ PLAN

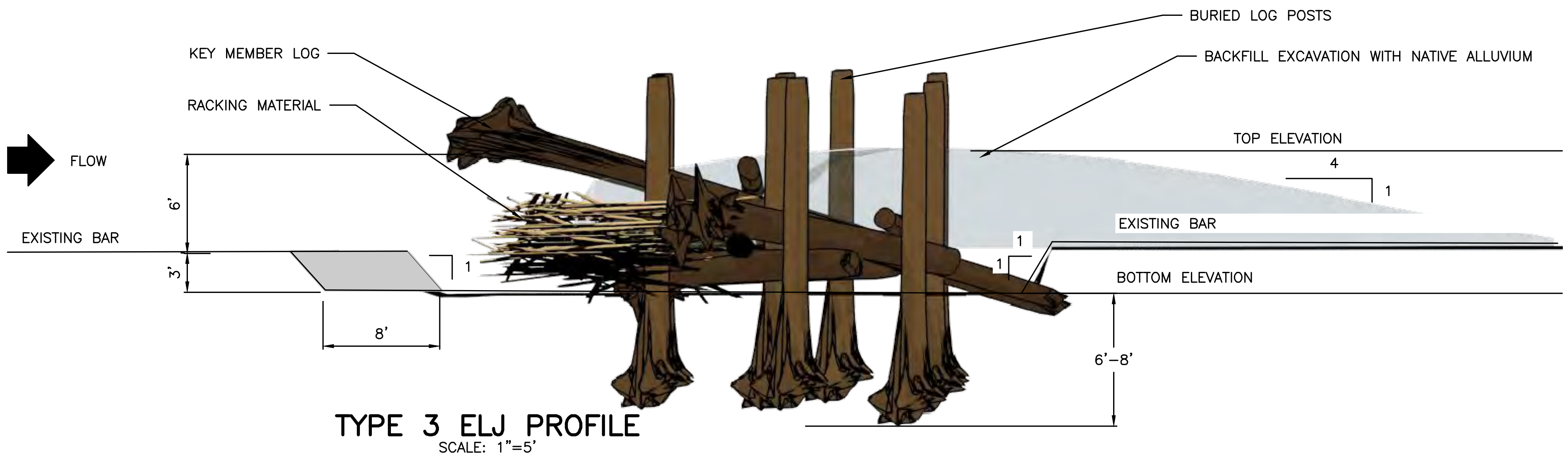
SCALE: 1"=10'

TYPE 3 STRUCTURE NOTES:

1. EXCAVATE IN FRONT OF LOGJAM FOR PLACEMENT OF RACKING MATERIAL. EXCAVATION AREA SHALL NOT BE BACKFILLED WITH ALLUVIUM, BUT LEFT AS A SCOUR HOLE.
2. EXCAVATION SPOILS SHALL BE STAGED ACCORDING TO THE SWPPP. SPOILS SHALL ALSO BE STOCKPILED TO ALLOW LOG LAYER PLACEMENT AND CONSTRUCTION ACCESS.
3. BACKFILL EXTENTS MAY VARY AND TO BE CONSTRUCTED WITH NATIVE ALLUVIUM FROM EXCAVATION SPOILS.
4. BACKFILL EACH STRUCTURE LAYER WITH NATIVE ALLUVIUM FLUSH WITH THE CURRENT LAYER PRIOR TO PLACEMENT OF THE SUBSEQUENT LAYER.
5. FINAL ELJ HEIGHT TO BE ACHIEVED AS SPECIFIED REGARDLESS OF ACTUAL LOG DIAMETERS USED OR STACKING ARRANGEMENT.
6. ALL LARGE WOOD DIMENSIONS DO NOT INCLUDE BARK THICKNESS.
7. COVER TOP OF BACKFILL AREA AND BASE OF STRUCTURES 6-12 INCHES WITH LOOSE WOOD DEBRIS AND CHIPS.
8. CABLE FRAME LOG MEMBERS PER INSTRUCTIONS ON LAYERING PLAN TO VERTICAL POSTS WITH 1/2 INCH GALVANIZED STEEL CABLE AND 4 CABLE CLAMPS PER LASHING. STAPLES WILL NOT BE USED TO FASTEN CABLE ENDS TOGETHER. ALL CLAMPS AND HAND SPLICING SHALL BE PER THE MANUFACTURER SPECIFICATIONS TIGHTEN CABLE TO APPROXIMATELY 500-POUNDS TENSION.
9. RACKING MATERIAL SHALL CONSIST OF APPROXIMATELY 500 INDIVIDUAL LOGS PER STRUCTURE WITH 6" - 12" DIA DBH AND A MINIMUM OF 5-FEET LENGTH. RACKING PLACEMENT SHALL OCCUR WITH EACH LAYER PLACEMENT TO ENSURE RACKING MATERIAL EXTENDS THROUGH STRUCTURE AND PINNED IN PLACE BY SUBSEQUENT LAYERS.
10. THE CONTRACTOR SHALL FIELD VERIFY WITH THE OWNER REPRESENTATIVE OR ENGINEER ALL STRUCTURE LOCATIONS, PILE LOCATIONS, LENGTHS, WIDTHS AND ELEVATIONS PRIOR TO EXCAVATION, ASSEMBLY AND INSTALLATION OF EACH STRUCTURE.
11. LOCATIONS FOR ALL STRUCTURE PLACEMENTS WILL BE STAKED IN FIELD BY THE ENGINEER OR OWNER REPRESENTATIVE PRIOR TO START OF CONSTRUCTION.
12. EXCAVATION LIMITS SHALL BE FIELD VERIFIED BY THE OWNER REPRESENTATIVE OR ENGINEER PRIOR TO EXCAVATION COMMENCING AND PLACEMENT OF ANY LARGE WOOD.
13. LOG TYPE IDENTIFICATION SHALL BE PAINTED ON ALL LOGS BY THE CONTRACTOR IN A PLACE VISIBLE FOR FIELD VERIFICATION PRIOR TO PLACEMENT WITH LEAD-FREE, BLAZE-ORANGE SURVEY MARKING PAINT.
14. THE WOOD LAYER PLACEMENT IN EACH LOGJAM LAYER SHALL BE FIELD VERIFIED BY ON-SITE OWNER REPRESENTATIVE PRIOR TO BACKFILLING.

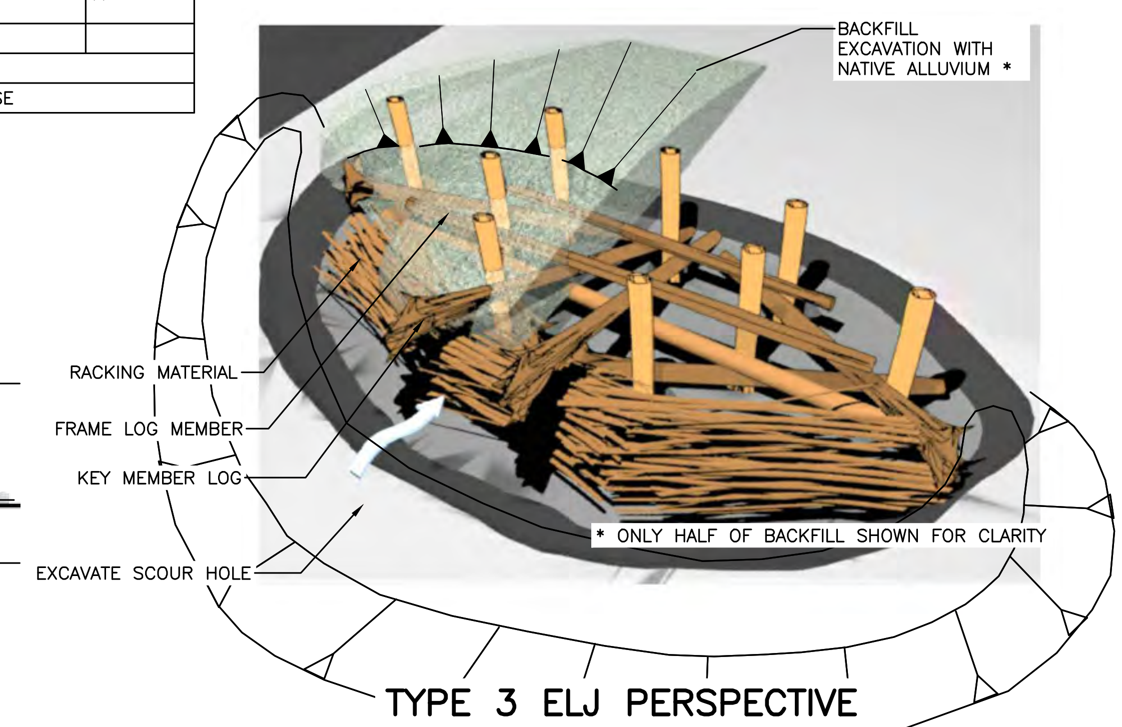
TYPE 3 STRUCTURE SCHEDULE

STRUCTURE LABEL*	**	**	**
STRUCTURE WIDTH, (FT)	**	**	**
STRUCTURE LENGTH, (FT)	**	**	**
SCOUR DEPTH, (FT)	**	**	**
MINIMUM FRAME LOG DIAMETER, (IN)	**	**	**
MINIMUM KEY LOG DIAMETER, (IN)	**	**	**
TIMBER POST DIAMETER, (IN)	**	**	**
GROUND ELEVATION AT STRUCTURE, (FT-NAVD88)	**	**	**
STRUCTURE BOTTOM ELEVATION, (FT-NAVD88)	**	**	**
TOP LOG ELEVATION, (FT-NAVD88)	**	**	**
STRUCTURE TOP ELEVATION, (FT-NAVD88)	**	**	**
MINIMUM PILE TIP ELEVATIONS, (FT-NAVD88)	**	**	**
AVERAGE SEPTEMBER WATER SURFACE ELEVATION (FT-NAVD 88)	**	**	**
* LABEL FORMAT, PHASE-ELJ TYPE-ELJ NUMBER			
**TBD - TO BE DETERMINED AND VERIFIED AT FINAL DESIGN PHASE			



TYPE 3 ELJ PROFILE

SCALE: 1"=5'



TYPE 3 ELJ PERSPECTIVE

Nov-08-2013 ---- CONCEPT DESIGN

0 Ø 1 IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.	NSEA NOOKSACK SALMON ENHANCEMENT ASSOCIATION Natural Systems Design	NAME OR INITIALS AND DATE DESIGNED -- CHECKED -- DRAWN -- CHECKED --	GEOGRAPHIC INFORMATION LATITUDE 48°49'00"N LONGITUDE 122°08'00"W TN/SC/RG T38N/S2/R5E DATE -	MIDDLE FORK NOOKSACK	TYPE 3 ELJ

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